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Systematic Development Of Methodologies In Planning Urban Water Resources For Medium Size Communities-- Calibration And Sensitivity Analysis Of The Continuous Runoff Simulation Model "Storm"

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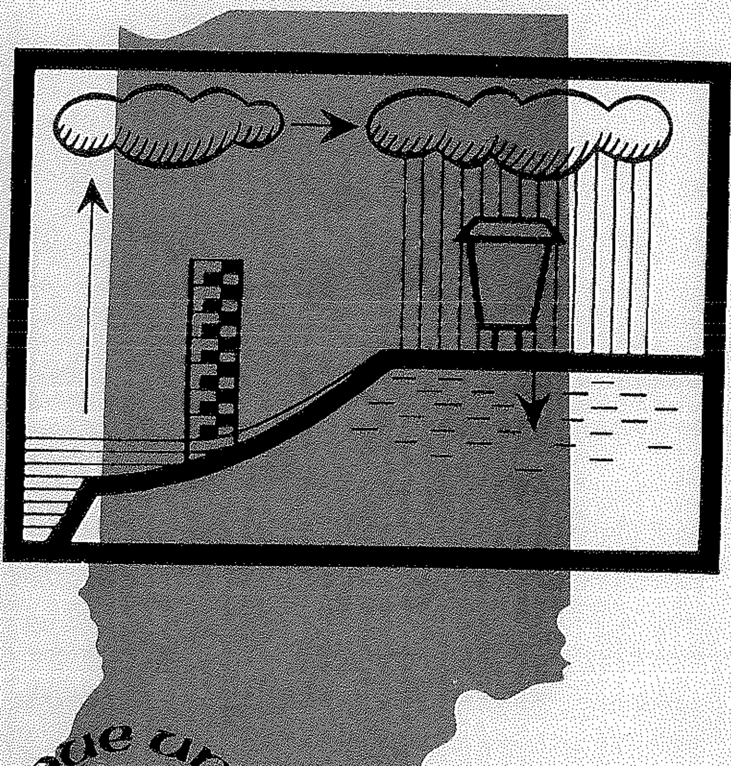

by

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May 1978

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ABSTRACT

This study relates to the hourly continuous runoff simulation model 'STORM' [1]. This model provides a substantial improvement over the elementary rainfall-runoff transformations, without being so sophisticated as to become cumbersome, in the practice by consulting engineer offices of small size. Using the composite runoff coefficient method in an urban watershed and in addition, the Soil Conservation Service method [3] for the pervious areas in a semi-urban watershed, a methodology is developed to calibrate the parameters characterizing the equations relating to each of these two methods. A sensitivity analysis of the model is done around the calibration values of the parameters.

In an urban area, the runoff coefficient for impervious surfaces is a decisive parameter. Usually the relative error in the runoff is of the same magnitude as the relative error in this parameter. The other parameters require less care in their determination.

In semi-urban areas the decisive parameter is the maximum soil moisture retention capacity. Its determination requires a laboratory analysis. Some empirical relations and a soil map provide good estimates for the other parameters.

The two methods of analysis show that the yearly total amount of runoff, the total amounts of runoff by storm event and the peaks by event are all good and stable estimates. The choice of the method

depends on the percent of imperviousness. Above 30% imperviousness the first method is recommended and around 30% of imperviousness, the use of both methods is suggested. A goodness-of-fit and a confidence interval calculation show that the amounts of runoff by event and the runoff peaks can be fitted by a Gamma distribution.

In addition the model STORM calculates hourly hydrograph ordinates. However, for the watershed under study it was not possible to obtain reliable results before the peak time, because of the short time of concentration which was approximately 30 minutes.

This study should provide the user with additional assistance and confidence in choosing the input parameters which require some degree of engineering judgement.

RESUME

Cette étude se rapporte à la simulation continue à intervalle d'une heure du ruissellement au moyen du modèle "STORM" [1]. Ce modèle apporte un perfectionnement considérable par rapport aux transformations pluies-débits élémentaires, sans toutefois devenir difficile à manier dans la pratique par des petits bureaux d'études. Le modèle emploie la méthode du coefficient de ruissellement composé pour les bassins urbains et la méthode du "Soil Conservation Service" [3] pour les surfaces perméables dans les bassins semi-urbains. On a développé une méthodologie pour l'étalonnage des paramètres qui caratérisent les équations se rapportant à chacune de ces méthodes. On a ensuite fait une analyse de la sensibilité du modèle aux erreurs dans les paramètres au voisinage de leurs valeurs d'étalonnage.

Dans une zone urbaine le coéfficient de ruissellement pour les surfaces imperméables est un paramètre décisif. En général, l'erreur relative du ruissellement est du même ordre de grandeur que l'erreur relative du paramètre. La détermination des autres paramètres exige moins de soin.

Dans les zones semi-urbaines le paramètre décisif est la capacité maximale de rétention de l'humidité du sol. Sa détermination nécessite une analyse de laboratoire. Quelques relations empiriques et les cartes des sols permettent des évaluations convenables des autres paramètres.

Les deux méthodes d'analyse montrent que la quantité totale de ruissellement annuel, la quantité de ruissellement par événement pluviométrique et les pics par événement sont des estimations convenables et stables. Le choix de la méthode dépend du pourcentage de surface imperméable. Au dessus de 30% de surface imperméable on recommande la première méthode et aux environs de 30% on suggère l'emploi des deux méthodes. Un test d'adjustement et un calcul d'intervalle de confiance montrent que les quantités de ruissellement par événement et les ruissellements maximums suivent une distribution Gamma.

De plus le modèle STORM calcule les ordonnées horaires de l'hydrogramme. Toutefois, pour le bassin étudié il n'a pas été possible d'obtenir des résultats fiables avant le temps de crue à cause du temps de concentration court qui est de l'ordre de 30 minutes.

Cette étude donne à l'utilisateur du modèle une aide et une confiance additionnelles dans le choix des paramètres d'entrèe qui exigent une certaine appréciation technique.

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INTRODUCTION

More from the point of view of the practitioner than that of the theorist inquirer, it is attempted in this report to develop a practical and workable method of using a hydrologic simulation model for the planning of drainage systems for small rural and urban areas. The principal objective is to convince small consulting engineer offices to consider and to use such a hydrologic model as an easy and better tool than the rational method. In this way, the continuous runoff simulation model "STORM" [1] is considered as a good, relative easy and useful tool. It has an acceptably small amount of parameters to determine and is especially useful at the planning stage or for preliminary designs. The results prove the appropriateness of the choice of this model.

Before using the model it is necessary to study it in depth and to understand the sensitivity of its results due to errors in its parameters and in the data input. The model "STORM" can be used with metric or English units. In the following discussion English units have been used.

The example watershed, the input parameters on which a sensitivity analysis was performed and the output data on which the calibration was based, are presented in Section 2 below. The sensitivity analysis procedure and results are presented in Section 3, followed by the conclusions of the analysis. First, the basic quantity functions of the model STORM are described in the following section.

CHAPTER 1

THE STORM MODEL

This study is limited to the rainfall-runoff function of STORM. The options involving snowmelt (unavailable data), diversion, storage and treatment are not considered.

The equations governing the total amount of runoff and the hourly hydrograph ordinates at a given point of a rural and/or urban watershed for each storm event considered by the model are listed in sections 1.1 through 1.3.

1.1 In a Rural Area

The model uses the following equation which was developed by the Soil Conservation Service and is part of the SCS Curve Number Technique [3]:

$$Q = \frac{(P-IA)^2}{P-IA+S} \tag{1}$$

where: A = accumulated runoff in inches

P = accumulated precipitation in inches

IA = initial abstraction in inches. Represents all initial losses (depression storage, interception, and infiltration during the filling of depression storage) that occur prior to the time when runoff begins.

S = total soil moisture capacity for storage of water in inches.

Since STORM is a continuous simulation model, it computes the soil moisture capacity (deficit) at the beginning of each time increment by the following equation:

$$S_t = S_{t-1} - IN * \Delta t + A * EV * \Delta t + B * MP * \Delta t \qquad (2)$$

where: $A = 0.7\left((SM - S_{t-1})/SM\right)^v \qquad (3)$

$B = \left((SM - S_{t-1})/SM\right)^p \qquad (4)$

S = soil moisture capacity for storage of water in inches

IN = maximum infiltration rate from initial abstraction in inches/hour

EV = pan evaporation rate in inches/hour

MP = maximum soil percolation rate in inches/hour

SM = maximum soil moisture capacity for storage of water in inches

t = time

Δt = 1 hour

v = exponent regulating evapotranspiration

p = exponent regulating percolation.

1.2 In an Urban Area

The runoff in an urban area is given by:

$$r = C(P-f) \qquad (5)$$

where: r = runoff in inches

C = composite runoff coefficient

P = rainfall/snowmelt in inches over the area

f = available depression storage in inches.

The composite runoff coefficient is computed by the equation:

$$C = C_p + (C_I - C_p) \sum_{i=1}^{L} X_i F_i \tag{6}$$

where: C_p = runoff coefficient for pervious surfaces

C_I = runoff coefficient for impervious surfaces

X_i = area in land use i, as a fraction of total urban watershed area

F_i = fraction of land use i that is impervious

L = total number of land uses.

The available depression storage is computed by the equation:

$$f = f_o + N_D k, \qquad f \le f_{max} \tag{7}$$

where: f_o = available depression storage, in inches, at the end of previous rainfall event

N_D = number of dry days since the end of previous rainfall event

k = pan evaporation rate, in inches/day, representing the recovery of depression storage

f_{max} = maximum depression storage in inches.

1.3 In a Semi-Urban Area

Due to the large pervious areas existing in single family dwelling areas for example, the use of the following equations is required:

(a) Equations (1), (2), (3), and (4) for the pervious areas;

(b) Equations (5), (6), and (7) for the impervious areas.

CHAPTER 2

WATERSHED AND INPUT-OUTPUT DATA

The STORM model is used on the "Upper Ross-Ade Watershed," West Lafayette, Indiana. The Upper Ross-Ade Watershed is residential and relatively uniform in character. The basin has a definite valley-type configuration. Woodland Avenue which runs down the center of the valley has slope of 1 to 3 percent, but some of the side streets are steeper. Yard slopes vary from nearly flat in the upper part of the basin to about 25 percent near the center of the basin (Figure 1).

The storm drainage is provided by an interceptor that runs down Woodland Avenue. Soils in the basin vary from Crosby silt loam of hydrologic group C in the flood plain to Miami silt loam of hydrologic group B on the steeper portions of the basin and Eel silt loam of hydrologic group C on the uplands. Almost half the roof drains have underground connections.

A Columbus-type deep-notch weir with a 6 foot crest length provides accurate flow measurement at the gaging site. Rainfall is collected at the weir site by a 16 inch diameter receiver located 8 feet above the ground.

The input data used in the sensitivity analysis are:

- hourly rainfall, in 1/100 of an inch, from April 20, 1970, through November 29, 1970, (225 days of record, 58 rainfall days);

- average pan evaporation in inches per day from January through December;
- some miscellaneous information about the dynamics of the soil, for example, the maximum soil storage capacity = 3.5 in, and the infiltration rate = .15 in/hr;
- the characteristics of the watershed: (shown in Fig. 1)

• total area	29 acres
• impervious area	11 acres (38%)
• pervious area (grass covered)	18 acres (62%)

The available measured and generated output data used for the calibration are:

- hourly runoff, in 1/100 of an inch, for the same period as for the rainfall;
- a detailed field observation of the study area for the interpretation of the input-output data.

Since the considered basin involves a large percent of impervious area (38%), it is not possible to test the model by considering only the equations developed for the pervious areas. Some attempts were made but the results were not satisfactory, since the values given to the parameters ultimately did not have any physical meaning. Consequently, only the urban area option and the semi-urban option were tested as reported in the following section.

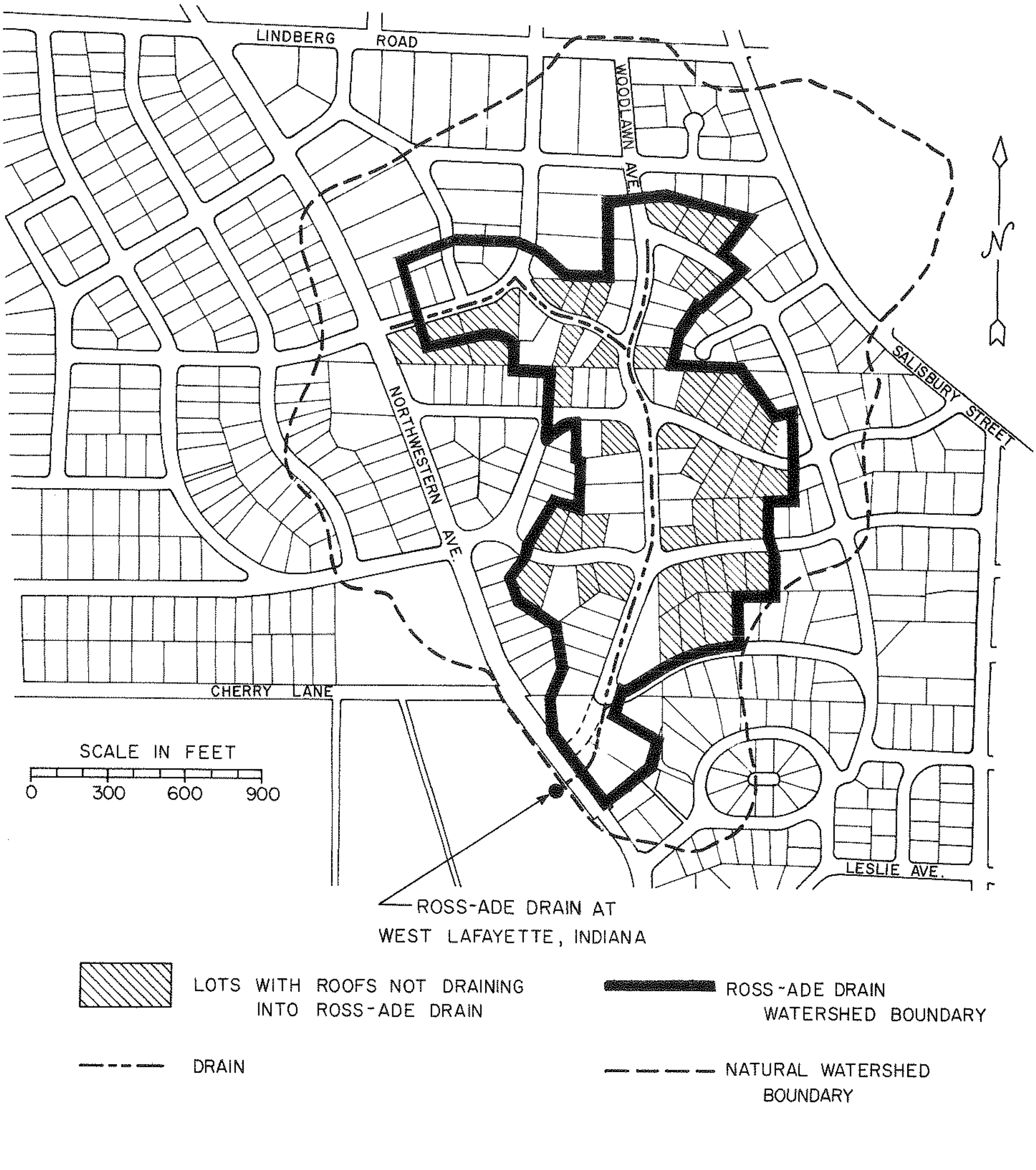

Figure 1 Upper Ross-Ade Watershed

CHAPTER 3

SENSITIVITY ANALYSIS PROCEDURE

Since the "Upper Ross-Ade Watershed" is a single family dwelling residential area, it is analyzed first as an urban area. It will be analyzed as a semi-urban area in Section 3.2.

3.1 Urban Area (Option I)

It is not always necessary to run a model to understand what would happen if the input data were modified. Instead, before running the model, it is very important to consider all the possible variations of the input data around practical and workable values of the parameters in order to visualize the model sensitivity to these changes in parameter values.

Definition: If A is the exact value of a certain quantity and a is an approximate value, then:

(a) the exact error of the approximate value a is:

$$\Delta a = A - a$$

(b) the relative error of the approximate value a is:

$$\delta_a = \frac{\Delta a}{a} \quad \text{[usually in \%]} \tag{8}$$

then:

$$A = a(1 + \delta_a) \tag{8a}$$

Thus the relative error δ_a of the variable a represents practically the correction which transforms an approximate value a into the correct value A. In the following only relative errors are considered as defined in Eq. (8) in determining the sensitivity of the composite runoff coefficient, of the depression storage and of the resulting runoff evaluation.

3.1.1 Error in the Composite Runoff Coefficient

The following notation is used in the calculation of the composite runoff coefficient:

Y_F = relative error in F

Y_P = relative error in C_P

Y_I = relative error in C_I

Z_F = relative error in C due to an error in F

Z_P = relative error in C due to an error in C_P

Z_I = relative error in C due to an error in C_I

Z_{PI} = relative error in C due to errors in C_P and C_I

Z_{FPI} = relative error in C due to errors in F, C_P and C_I.

Four land uses are considered separately, one at a time. They have the following characteristics:

$$\left.\begin{array}{ll} \text{A : commercial area} & : i = 1,\ F_1 = .90 \\ \text{B : industrial area} & : i = 2,\ F_2 = .70 \\ \text{C : multiple family area} & : i = 3,\ F_3 = .50 \\ \text{D : single family area} & : i = 4,\ F_4 = .30 \end{array}\right\} \text{with} \left\{\begin{array}{l} C_p = .30 \\ C_I = .90 \\ X_i = 1.00 \\ L = i \end{array}\right.$$

The behavior of the error in C is examined as a function of Y_F, Y_P, Y_I for each land use. For a single land use, Eq. (6) becomes:

$$C = C_P + (C_I - C_P)F_i \qquad (6a)$$

3.1.1.1 Calculation of Simple Errors in the Composite Runoff Coefficient

The relative errors Z_F, Z_P and Z_I in C due to a relative error Y_F or Y_P or Y_I in F, C_P or C_I, respectively, are obtained from Eq. (6a) making use of definition (8):

$$Z_F = \pm Y_F \left(1 - \frac{C_P}{C}\right) \tag{9}$$

$$Z_P = \pm Y_P \frac{C_P}{C} (1-F) \tag{10}$$

$$Z_I = \pm Y_I \frac{C_I}{C} F \tag{11}$$

Relationships 9, 10 and 11 are presented graphically for each land use in Fig. 2. It is seen, for example, that an error in C_P of +233% gives an error in C of 102% for a single family area, of 58% for a multiple family area, of 29% for an industrial area, and only 8% for a commercial area. Likewise an error of -100% in F results in an error in C of -38% in a single family area, of -50% in a multiple family area, of -58% in an industrial area, and -64% in a commercial area; and an error of +11% in C_I yields errors of 6%, 8%, 10% and 11% in the same four areas, respectively.

3.1.1.2 Calculation of Z_{PI}

Since the area F can be obtained with good accuracy from field measurements or from aerial or satellite photography, the principal source of error is in the estimates of C_P and C_I. The relative error Z_{PI} in C due to simultaneous relative errors Y_P and Y_I in C_P and in C_I, respectively, is obtained from Eq. (6a) and from using the definition of Eq. (8):

$$Z_{PI} = Y_I \frac{C_I}{C} F + Y_P \frac{C_P}{C} (1-F) \tag{12}$$

Typical values of Z_{PI} calculated for each land use are given in Table 1 and are plotted in Fig. 3. For any value of Y_I or Y_P smooth variations of Z_{PI} are obtained for variations of Y_P or of Y_I respectively. It is seen, for example, that errors in C_I of -10%, and in C_P of -100% result in an error in C of approximately -50% for a single family area.

3.1.1.3 Calculation of Z_{FPI}

The relative error Z_{FPI} in C due to simultaneous relative errors Y_F, Y_P and Y_I in F, C_P, and Z_I, respectively, is obtained from Eq. (6a), and using the definition of Eq. (8), is found to be (see Appendix A for derivation)

$$Z_{FPI} = Y_P \frac{C_P}{C} + \frac{F}{C}\left[C_I(Y_F + Y_F Y_I + Y_I) - C_P(Y_F + Y_F Y_P + Y_P)\right] \quad (13)$$

Z_{FPI} is presented graphically for the commercial area only in Fig. 4. It may be seen that for the commercial area, errors in C_I and F of -20% and in C_P of -100% result in an error in C of -36%.

3.1.1.4 Statistics of Z_{PI}

Consider a well distributed area with each of the 4 land uses A, B, C, D, occupying 25% of the total area. The following statistics are computed for this composite land use:

- the mean of the absolute values of Z_{PI}: $\overline{|Z_{PI}|}$
- the standard deviation of the absolute values of Z_{PI}: $\sigma_{|Z_{PI}|}$
- the coefficient of variation of the absolute value of Z_{PI}: $C_v = \overline{|Z_{PI}|} / \sigma_{|Z_{PI}|}$

These three statistics are presented graphically in Figures 5, 6, and 7, respectively. It is seen, for example, that errors Y_I = -10% and Y_P = 80% result in a $|Z_{PI}|$ = 12%, $\sigma_{|Z_{PI}|}$ = 14% and cv = 1.17.

3.1.1.5 Conclusions on the Composite Runoff Coefficient Determination

The above results on the behavior of the error in C as a function of the error in its components, can be summarized as follows:

- the relative error of the impervious surface runoff coefficient is a decisive one (see Figures 2 through 7);
- the influence of the relative error of the impervious surface runoff coefficient is practically the same in each land use or combination of different land uses (see Figures 2 and 3);
- the relative error of the composite runoff coefficient is of the same magnitude as the relative error of the impervious surface runoff coefficient (see Figure 3);
- the influence of the relative error in the pervious surface runoff coefficient depends on the area considered (see Figures 2 and 3);
- an underestimation of the pervious surface runoff coefficient is less serious than an overestimation (see Figures 5 and 6).

3.1.2 Error in the Depression Storage

Usually the range of values of the depression storage is 1/16 in $\leq f \leq$ 1/4 in, the extremes corresponding to totally impervious and totally pervious areas respectively. For intermediate degrees of imperviousness f_{max} can be estimated from

$$f_{max} = .25(1.0 - IMP) + .06\ IMP$$

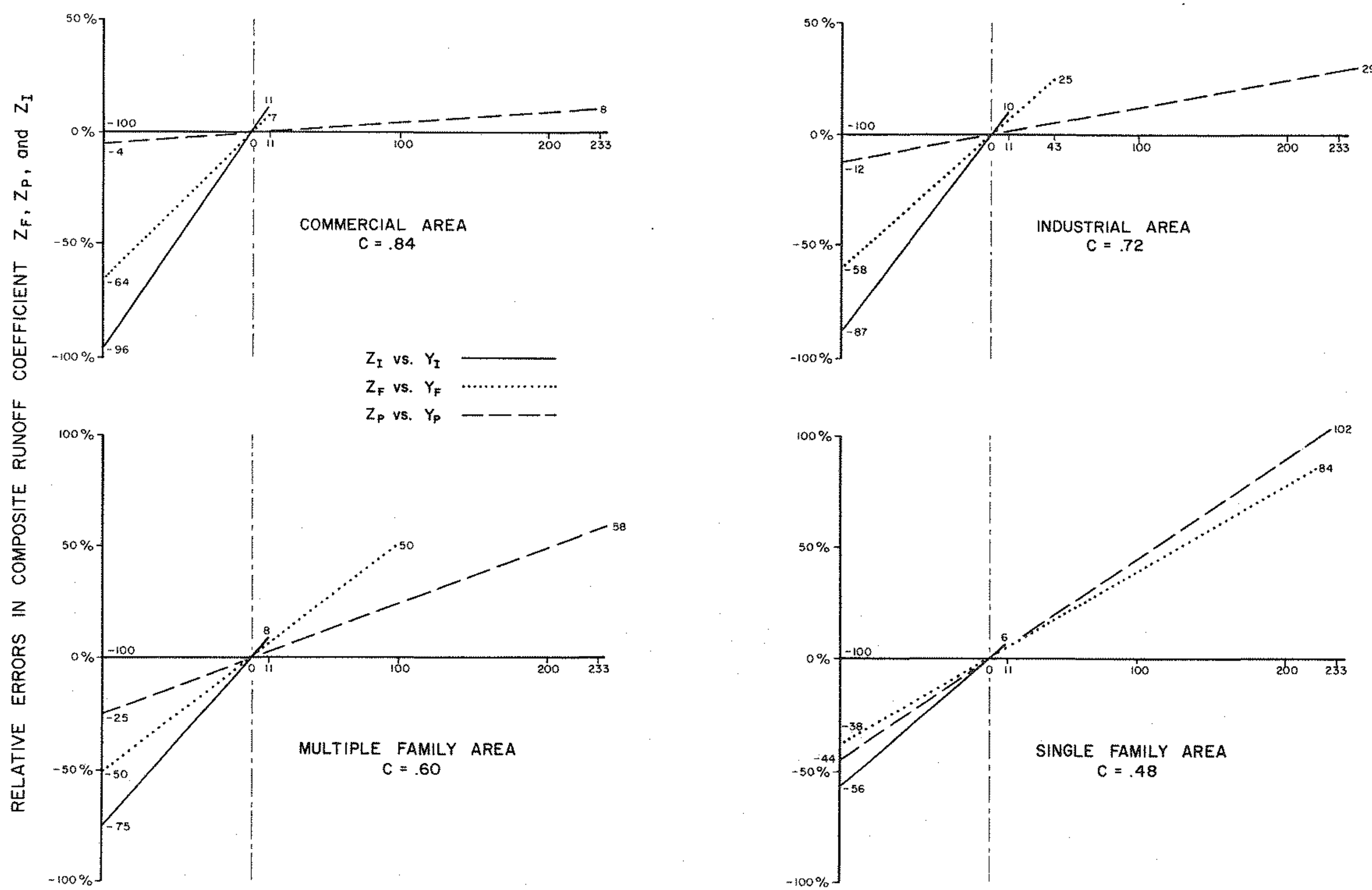

Figure 2 Relative Errors Z_F, Z_p, Z_I in C Due to Relative Errors Y_F, Y_p, Y_I in F, C_p and C_I

Table 1 Relative Error (Z_{PI}) in C Due to Relative Errors (Y_P, Y_I) in C_P and C_I Simultaneously

A : COMMERCIAL AREA (C = .84)

Y_I \ Y_P	-1.00	-0.80	-0.60	-0.40	-0.20	0.0	0.20	0.40	0.60	0.80	1.00
.10	.06	.07	.07	.08	.09	.10	.10	.11	.12	.13	.13
0	-.04	-.03	-.02	-.01	-.01	0	.01	.01	.02	.03	.04
-.10	-.13	-.13	-.12	-.11	-.10	-.10	-.09	-.08	-.07	-.07	-.06
-.20	-.23	-.22	-.21	-.21	-.20	-.19	-.19	-.18	-.17	-.16	-.16
-.30	-.32	-.32	-.31	-.30	-.30	-.29	-.28	-.27	-.27	-.26	-.25
-.40	-.42	-.41	-.41	-.40	-.39	-.39	-.38	-.37	-.36	-.36	-.35
-.50	-.52	-.51	-.50	-.50	-.49	-.48	-.47	-.47	-.46	-.45	-.45
-.60	-.61	-.61	-.60	-.59	-.59	-.58	-.57	-.56	-.56	-.55	-.54
-.70	-.71	-.70	-.70	-.69	-.68	-.67	-.67	-.66	-.65	-.65	-.64
-.80	-.81	-.80	-.79	-.79	-.78	-.77	-.76	-.76	-.75	-.74	-.74
-.90	-.90	-.90	-.89	-.88	-.87	-.87	-.86	-.85	-.85	-.84	-.83
-1.00	-1.00	-.99	-.99	-.98	-.97	-.96	-.96	-.95	-.94	-.94	-.93

B : INDUSTRIAL AREA (C = .72)

Y_I \ Y_P	-1.00	-0.80	-0.60	-0.40	-0.20	0.0	0.20	0.40	0.60	0.80	1.00
.10	-.04	-.01	.01	.04	.06	.09	.11	.14	.16	.19	.21
0	-.12	-.10	-.07	-.05	-.02	0	.02	.05	.07	.10	.12
-.10	-.21	-.19	-.16	-.14	-.11	-.09	-.06	-.04	-.01	.01	.04
-.20	-.30	-.27	-.25	-.22	-.20	-.17	-.15	-.13	-.10	-.08	-.05
-.30	-.39	-.36	-.34	-.31	-.29	-.26	-.24	-.21	-.19	-.16	-.14
-.40	-.47	-.45	-.42	-.40	-.37	-.35	-.32	-.30	-.27	-.25	-.22
-.50	-.56	-.54	-.51	-.49	-.46	-.44	-.41	-.39	-.36	-.34	-.31
-.60	-.65	-.62	-.60	-.57	-.55	-.52	-.50	-.47	-.45	-.42	-.40
-.70	-.74	-.71	-.69	-.66	-.64	-.61	-.59	-.56	-.54	-.51	-.49
-.80	-.82	-.80	-.77	-.75	-.72	-.70	-.67	-.65	-.62	-.60	-.57
-.90	-.91	-.89	-.86	-.84	-.81	-.79	-.76	-.74	-.71	-.69	-.66
-1.00	-1.00	-.97	-.95	-.92	-.90	-.87	-.85	-.82	-.80	-.77	-.75

Table 1 (cont'd)

C : MULTIPLE FAMILY AREA (C = .60)

Y_I \ Y_P	-1.00	-0.80	-0.60	-0.40	-0.20	0.0	0.20	0.40	0.60	0.80	1.00
.10	-.17	-.13	-.08	-.03	.02	.07	.12	.17	.22	.27	.32
0	-.25	-.20	-.15	-.10	-.05	0	.05	.10	.15	.20	.25
-.10	-.32	-.27	-.22	-.17	-.12	-.07	-.02	.03	.08	.13	.17
-.20	-.40	-.35	-.30	-.25	-.20	-.15	-.10	-.05	.00	.05	.10
-.30	-.47	-.42	-.38	-.32	-.27	-.22	-.17	-.12	-.07	-.02	.03
-.40	-.55	-.50	-.45	-.40	-.35	-.30	-.25	-.20	-.15	-.10	-.05
-.50	-.63	-.57	-.52	-.47	-.42	-.38	-.32	-.27	-.22	-.17	-.13
-.60	-.70	-.65	-.60	-.55	-.50	-.45	-.40	-.35	-.30	-.25	-.20
-.70	-.77	-.72	-.67	-.62	-.57	-.52	-.47	-.42	-.37	-.32	-.27
-.80	-.85	-.80	-.75	-.70	-.65	-.60	-.55	-.50	-.45	-.40	-.35
-.90	-.92	-.87	-.82	-.77	-.72	-.67	-.62	-.57	-.52	-.47	-.42
-1.00	-1.00	-.95	-.90	-.85	-.80	-.75	-.70	-.65	-.60	-.55	-.50

D : SINGLE FAMILY AREA (C = .48)

Y_I \ Y_P	-1.00	-0.80	-0.60	-0.40	-0.20	0.0	0.20	0.40	0.60	0.80	1.00
.10	-.38	-.29	-.21	-.12	-.03	.06	.14	.23	.32	.41	.49
0	-.44	-.35	-.26	-.17	-.09	0	.09	.17	.26	.35	.44
-.10	-.49	-.41	-.32	-.23	-.14	-.06	.03	.12	.21	.29	.38
-.20	-.55	-.46	-.37	-.29	-.20	-.11	-.03	.06	.15	.24	.32
-.30	-.61	-.52	-.43	-.34	-.26	-.17	-.08	.01	.09	.18	.27
-.40	-.66	-.57	-.49	-.40	-.31	-.22	-.14	-.05	.04	.12	.21
-.50	-.72	-.63	-.54	-.46	-.37	-.28	-.19	-.11	-.02	.07	.16
-.60	-.77	-.69	-.60	-.51	-.42	-.34	-.25	-.16	-.08	.01	.10
-.70	-.83	-.74	-.66	-.57	-.48	-.39	-.31	-.22	-.13	-.04	.04
-.80	-.89	-.80	-.71	-.62	-.54	-.45	-.36	-.27	-.19	-.10	-.01
-.90	-.94	-.86	-.77	-.68	-.59	-.51	-.42	-.33	-.24	-.16	-.07
-1.00	-1.00	-.91	-.82	-.74	-.65	-.56	-.47	-.39	-.30	-.21	-.13

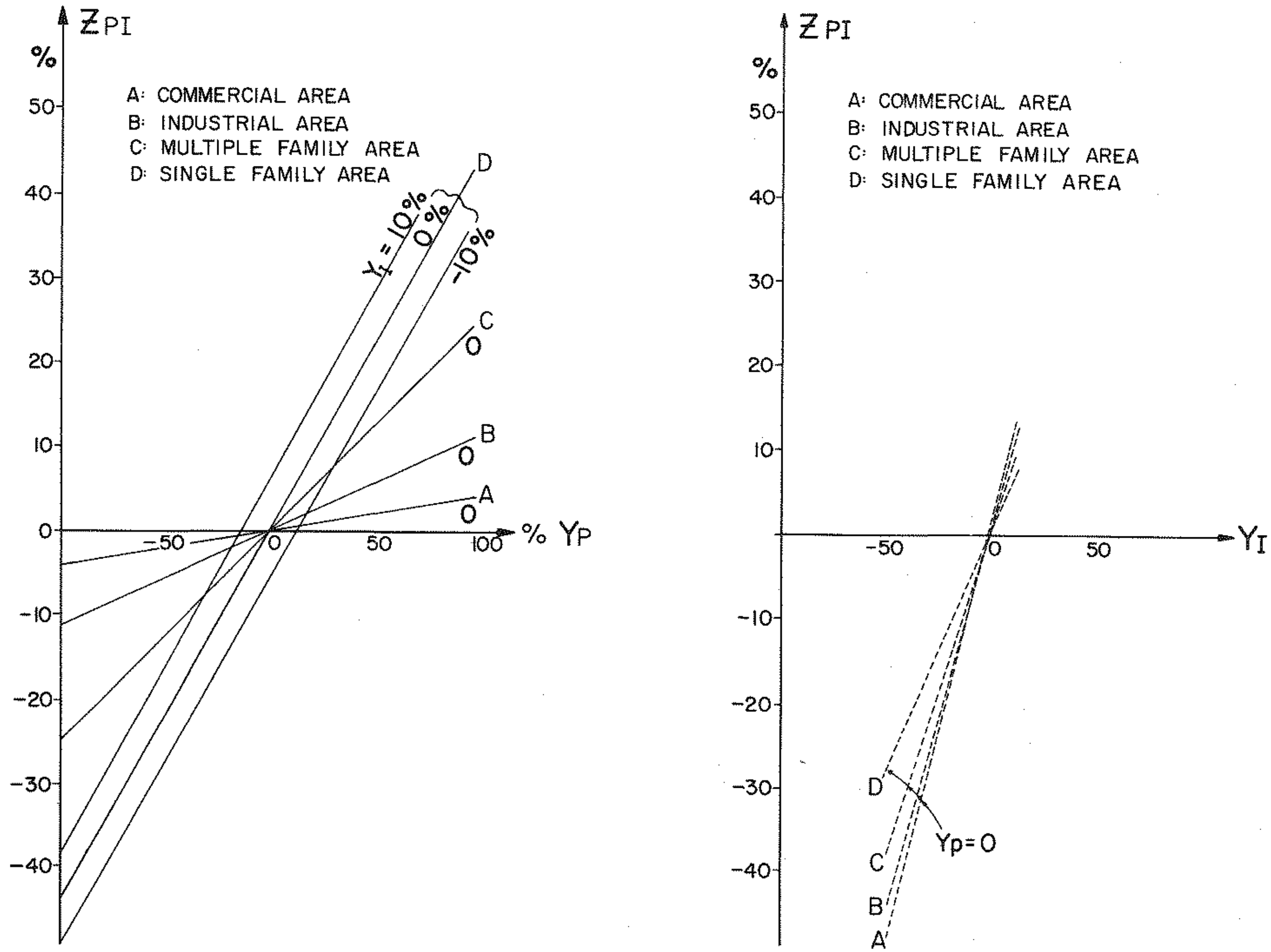

Figure 3 Variation of the Relative Error Z_{PI} in C Due to Variations of the Relative Error Y_p and Y_I in C_p and C_I

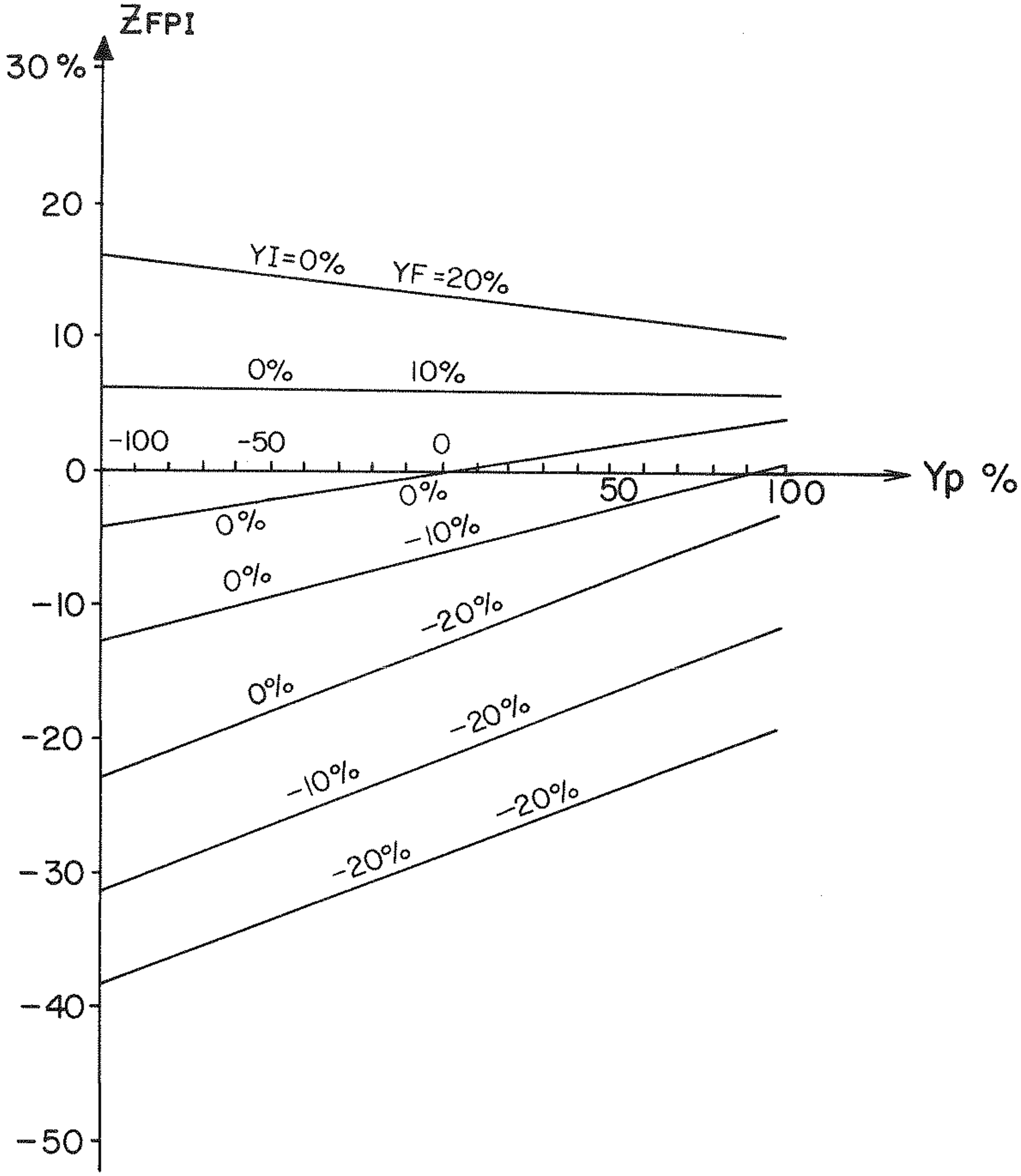

Figure 4 Variation of the Relative Error Z_{FPI} in C Due to Some Variations of the Relative Errors Y_P, Y_I, Y_F in F, C_P and C_I for the Commercial Area

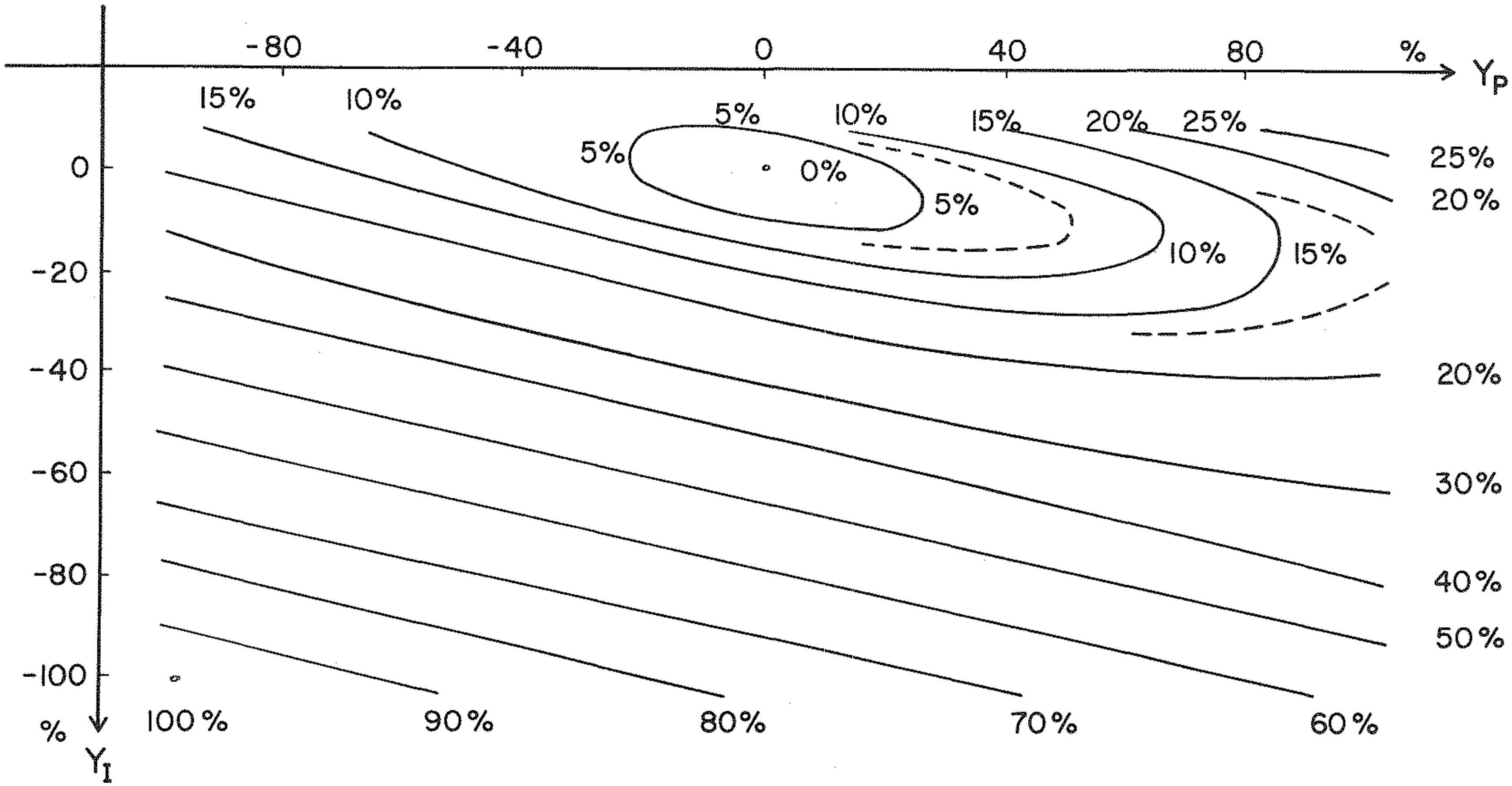

Figure 5 Behavior of the Mean of the Absolute Values of the Relative Error Z_{PI} in C as a Function of the Relative Errors (Y_I, Y_P) in C_P and C_I for the Distributed Area

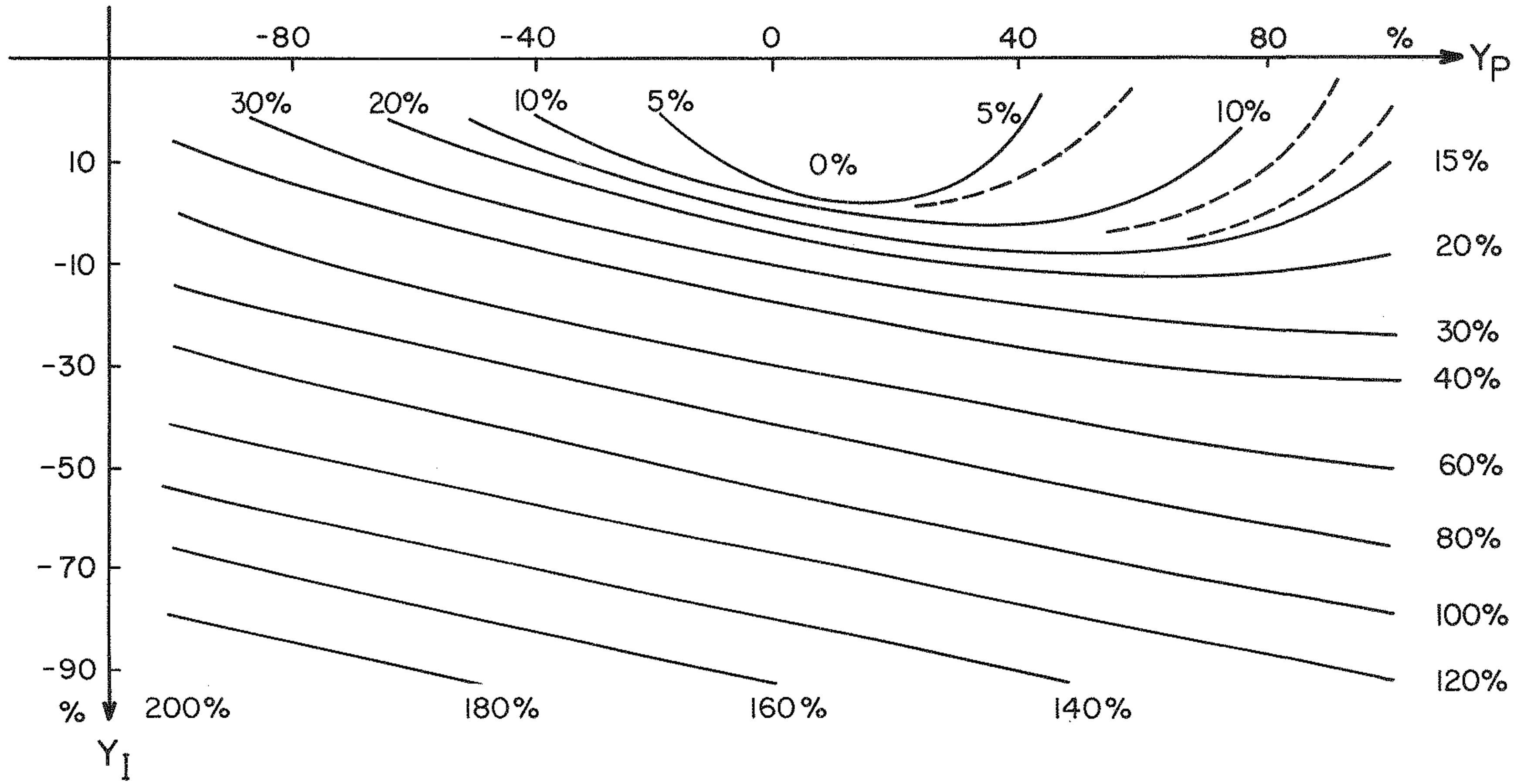

Figure 6 Behavior of the Standard Deviation of the Absolute Values of the Relative Error Z_{PI} in C as a Function of the Relative Errors (Y_I, Y_p) in C_p and C_I for the Distributed Area

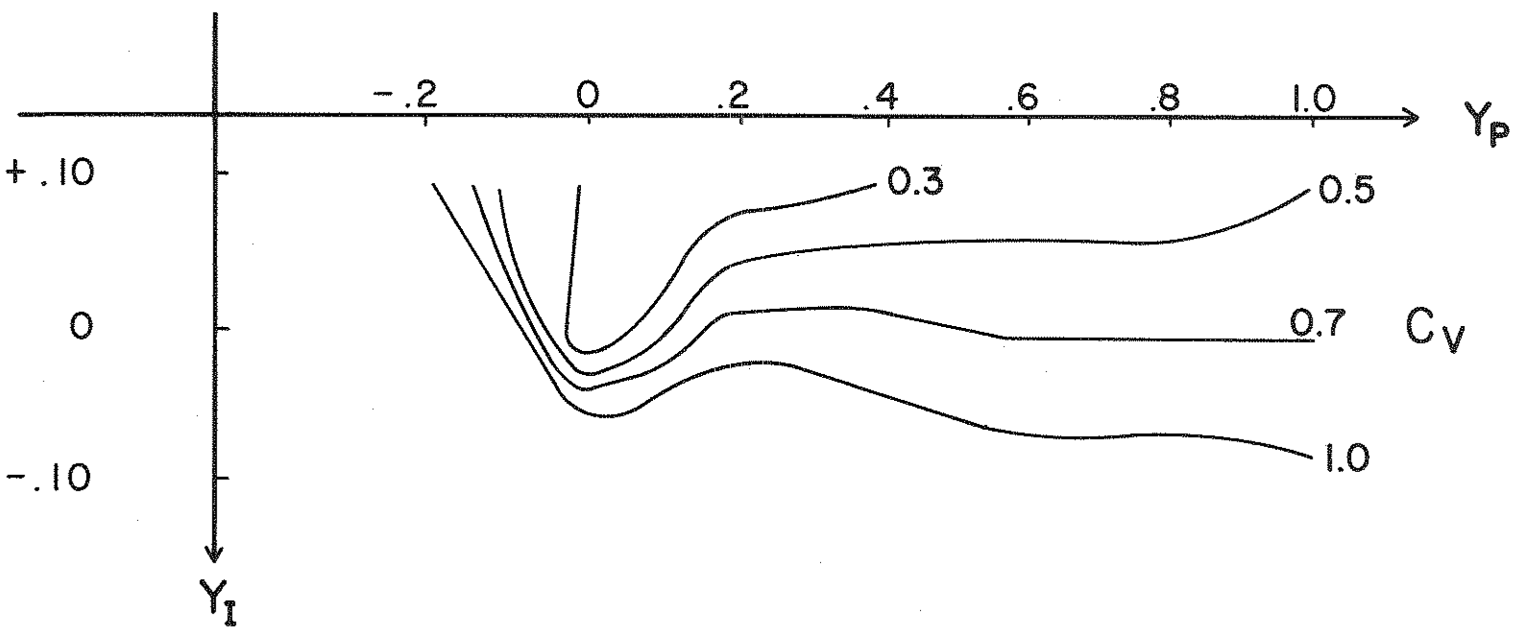

Figure 7 Approximate Behavior of the Coefficient of Variation (C_v) of Z_{PI} as a Function of the Relative Errors (Y_I, Y_P) in C_P and C_I for the Distributed Area

where: IMP = percent imperviousness. It is seen that for fully impervious and fully pervious surfaces, respectively, the maximum depression storages correspond to the extremes of the range given above. A better estimation of f_{max} is not necessary for the initial calibration, given the general accuracy of the model.

3.1.3 Error in the Estimated Runoff

The error in the estimated runoff due to errors in the rainfall data and in the composite runoff coefficient is obtained from Eq. (5) and from using the definition of Eq. (8). In Eq. (5) the available depression storage, f, is assumed negligible compared to the rainfall P (see derivation in Appendix A):

$$Z_{RC} = Y_R + Y_C + Y_R Y_C \tag{15}$$

where: Z_{RC} = relative error in the runoff due to errors in C and in P

Y_R = relative error in the rainfall

Y_C = relative error in the composite runoff coefficient

Relationship (15) is plotted in Fig. 8. The relative error in the runoff is seen to vary smoothly from -50% to +70% for a corresponding variation in relative errors in R and in C from -30% to +30%.

3.1.4 Calibration

The calibration of the model requires the determination of three parameters: the runoff coefficients C_P and C_I, respectively, and the maximum depression storage f_{max}. From Fig. 8 it is seen that there is an infinite number of possible sets of values of the rainfall and of the composite runoff coefficient which yield zero error, but only a few have the correct physical significance and are acceptable.

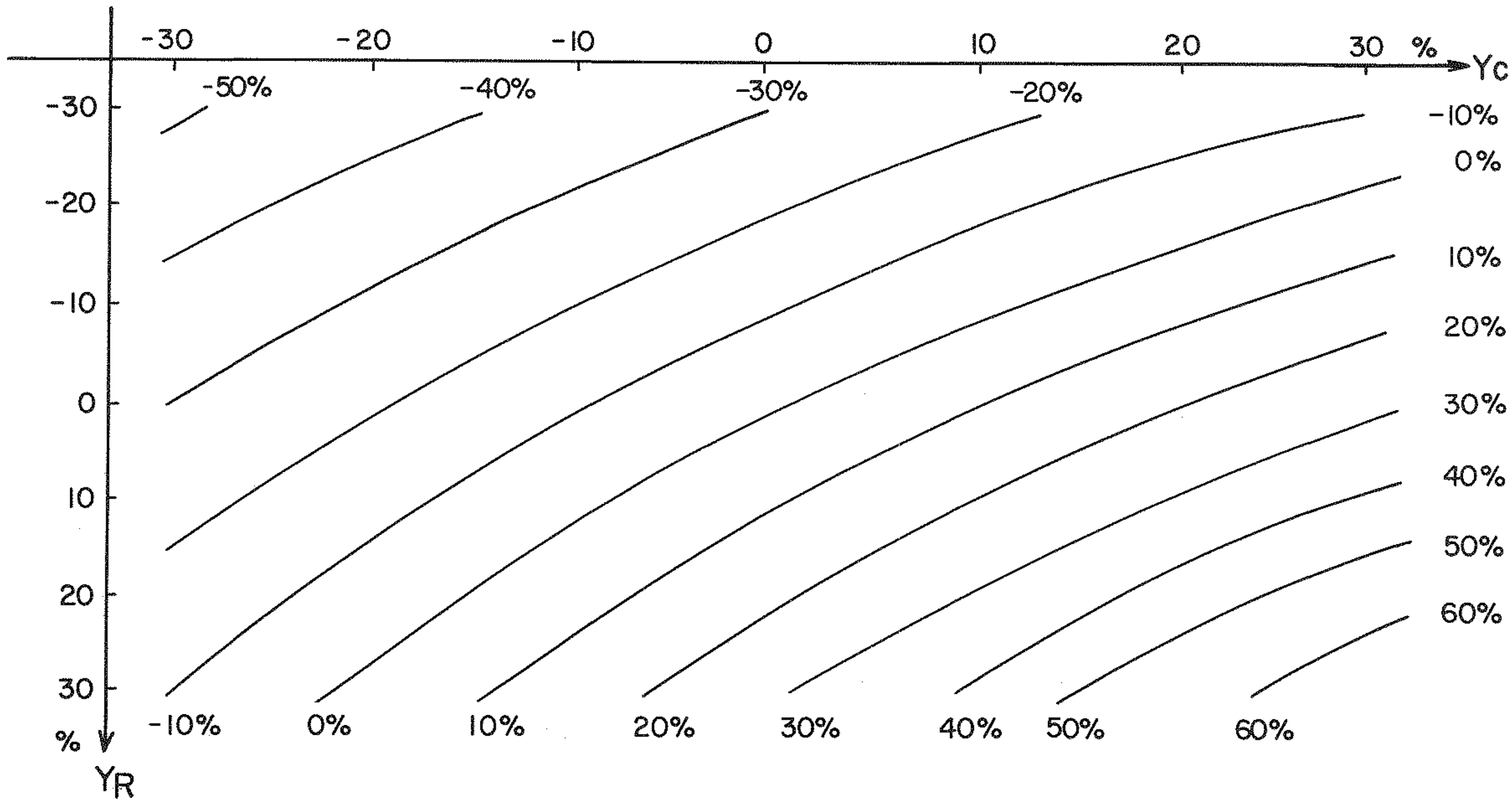

Figure 8 Variation in the Relative Error Z_{RC} in the Runoff Due to Some Relative Errors Y_R, Y_C in the Rainfall and in the Composite Runoff Coefficient, Respectively

An example of finding the acceptable values of the parameters C_p, C_I, and f_{max} is given for the Upper Ross-Ade Watershed. The following data are used:

(a) input data: total of hourly rainfall data for 1970 24.9 in

fraction of land that is impervious, F 0.38

measured runoff for the same period 3.05 in

(b) $f_{max} = .25(1\text{-IMP}) + .06\ \text{IMP} =$ 0.18 in

(c) there are about 40 events where the rainfall exceeds the depression storage f_{max}

(d) from Eq. (5) the composite runoff coefficient is

$$C = r/(P-f) = 3.05/(24.9 - 40 \times 0.18) = 0.18$$

(e) from Eq. (6) $C = C_p + (C_I - C_p)\ F = 0.18$, it is seen that C_I and C_p take the following extreme values

$$\begin{cases} C_I \max = .47 \\ C_p \min = 0 \end{cases} \qquad \begin{cases} C_I = .18 \\ C_p = .18 \end{cases}$$

and the intermediate values vary linearly between these as shown in Figure 9.

(f) As shown in Fig. 1, the majority of the roofs do not drain in the sewer, but drain on the grass. This justifies a low value for C_I and a large difference between C_I and C_p.

(g) Therefore a good range for the parameters is:

$$.18 \leq f \leq .25$$

$$.30 \leq C_I \leq .40$$

$$.05 \leq C_p \leq .10$$

(h) The model is run with these preliminary estimates of f_{max}, C_I and C_p, and the final calibration is made on the basis of matching the calculated and observed total amounts of runoff.

The values of the calibrated input data are grouped in Table 2.

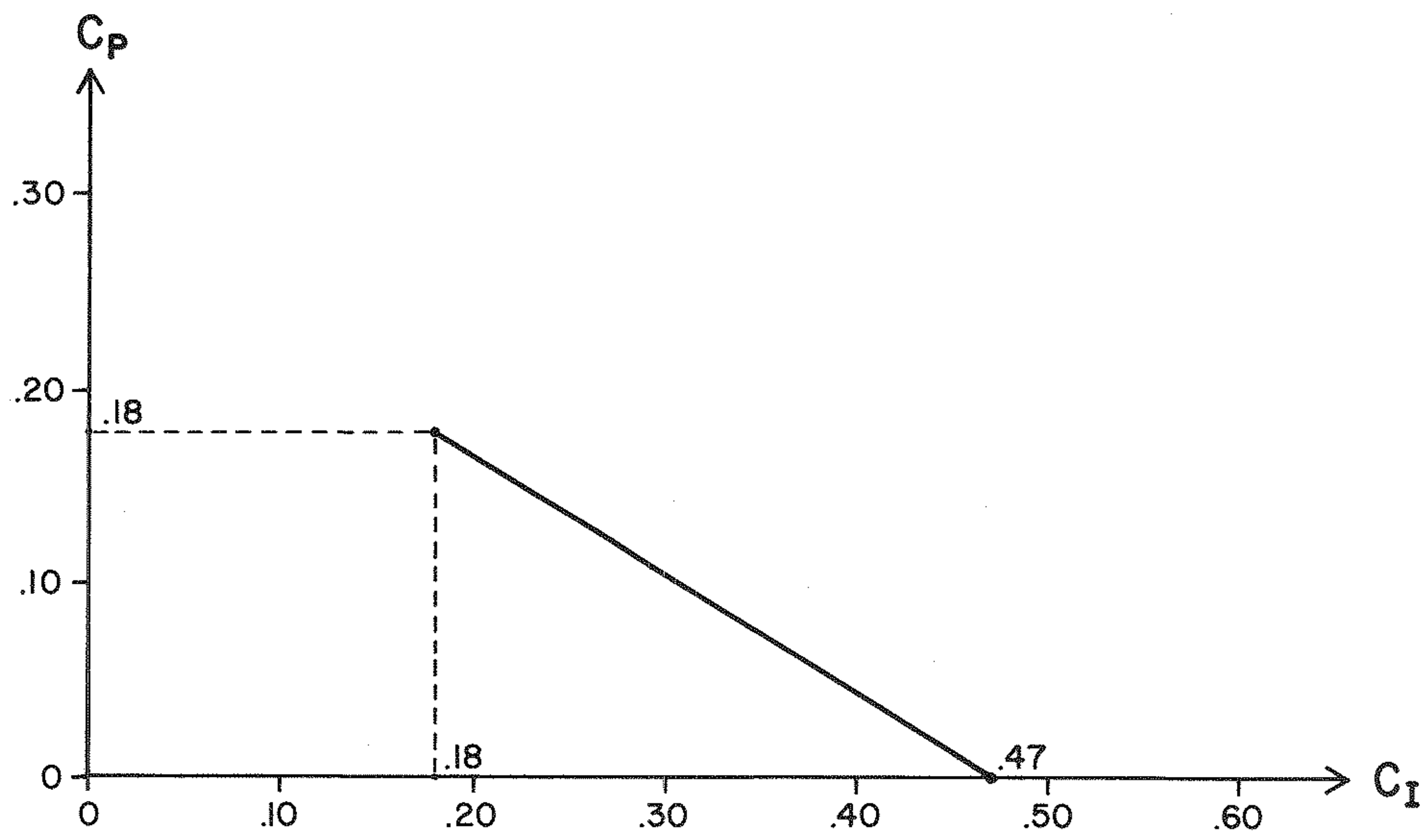

Figure 9 Variation of the Coefficients of Runoff for Pervious and Impervious Areas

Table 2 List of Calibrated Input Parameters

OPTION I	OPTION II
URBAN AREA	SEMI-URBAN AREA
Composite Runoff Coefficient Method	Impervious Areas: Composite Runoff Coefficient Method Pervious Areas: SCS Method
	Single Family Housing: $F = 0.38$
$C_P = 0.08$	$IA_{max} = 0.70$ in $S_{max} = 3.50$ in
$C_I = 0.34$	$IA_{initial} = 0.25$ in $S_{initial} = 1.50$ in
$f_{max} = 0.23$	$ERC = v = 3.0$ $IN = 0.03$ in/hr
	$p = 1.0$ $MP = 0.05$ in/hr

Pan Evaporation Data: monthly values in inches/day from January to December

0, 0, 0, 0.15, 0.14, 0.22, 0.29, 0.18, 0.14, 0.11, 0.02, 0.

3.1.5 Evaluation of Results (Final Calibration)

3.1.5.1 Total Amount of Runoff per Event

With the set of chosen calibrated input values, Table 2, the model computes the runoff and determines the number of events for which the rainfall exceeds the maximum depression storage. In this case there are 42 such events selected by the model. Then, the total amount of the observed runoff (3.05 in) is distributed in time among the 42 events corresponding as closely as possible to the 42 events selected by the model. The empirical distribution(s) of:

- the set of 42 observed runoff values is shown in Figure 10;
- the set of 42 computed runoff values is shown in Figure 11;
- the sets of the observed and computed values are compared in Figure 12;
- the set of the 42 squared deviations (observed-computed) is shown in Figure 13.

For the convenience of the graphical presentation the runoff values have been multiplied by a scale factor (defined in the following paragraph) shown in the respective figures. In Figure 12 the scale factors for the observed and computed runoff values are those shown in Figures 10 and 11, respectively. Also shown on the figures are the mean, the standard deviation (sigma) and the coefficient of variation of each set of values. The mean of the observed and calculated runoff values are almost the same but the calculated values have a slightly smaller (4.6%) standard deviation (and hence coefficient of variation) than the observed values.

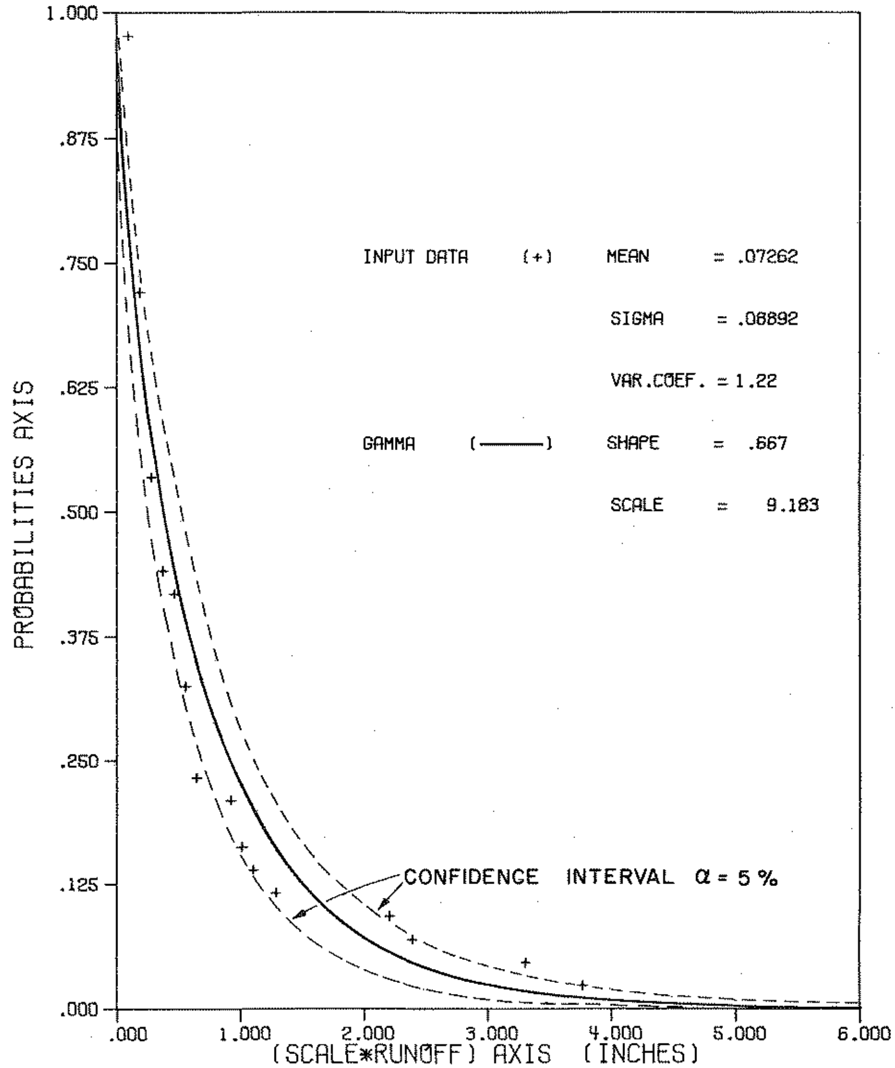

Figure 10 Distribution of Observed Runoff by Event (Option I)

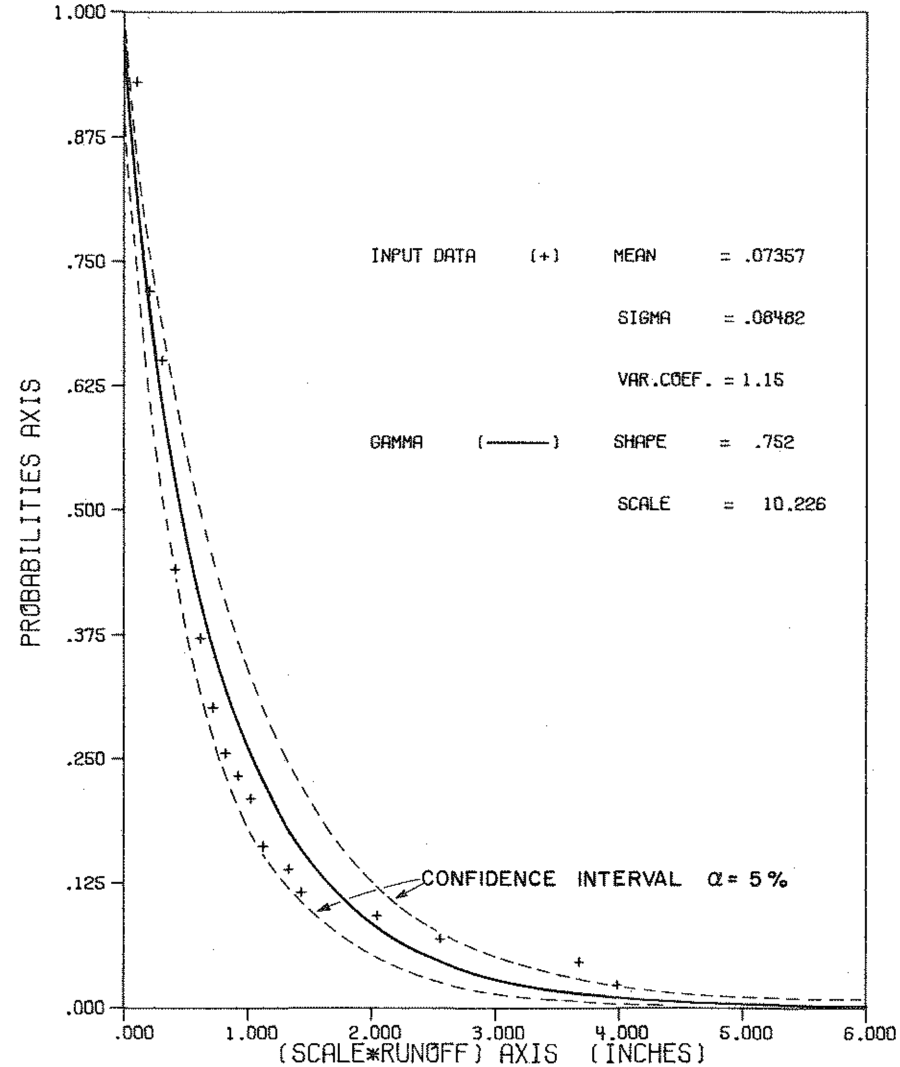

Figure 11 Distribution of Computed Runoff by Event (Option I)

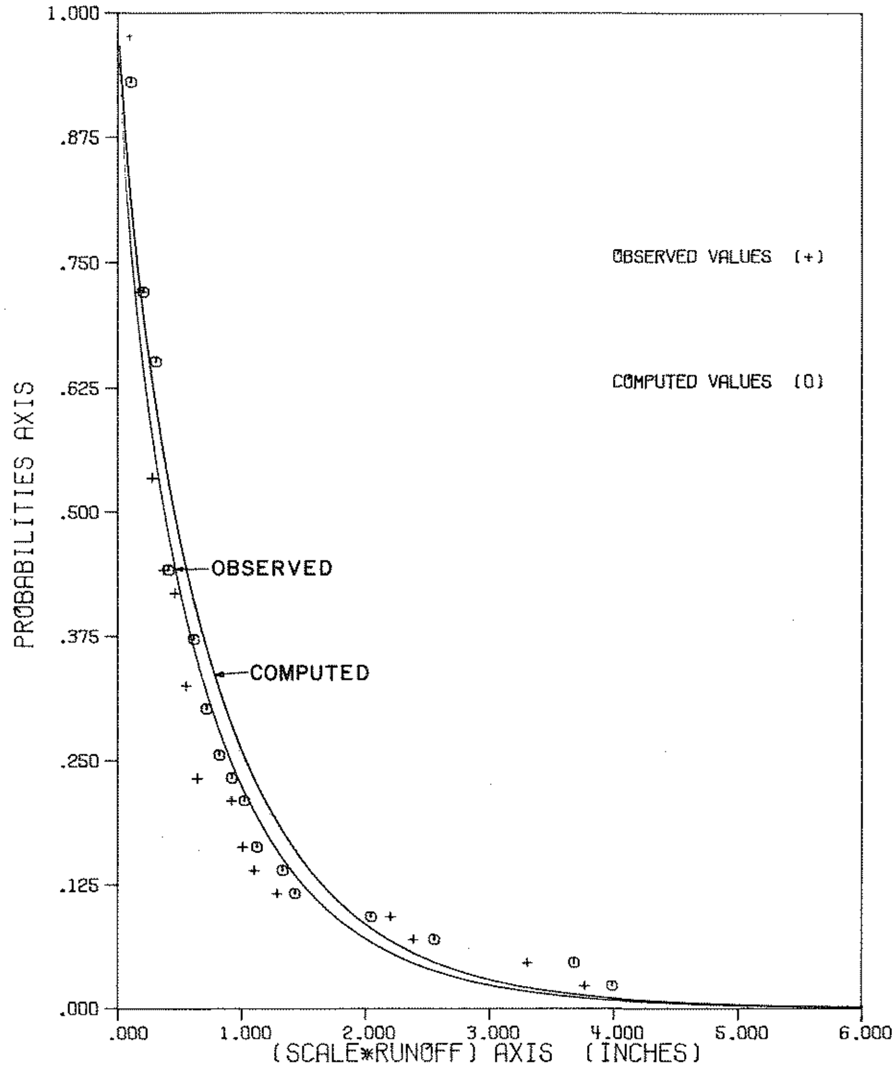

Figure 12 Distributions of Observed and Computed Runoff by Event (Option I)

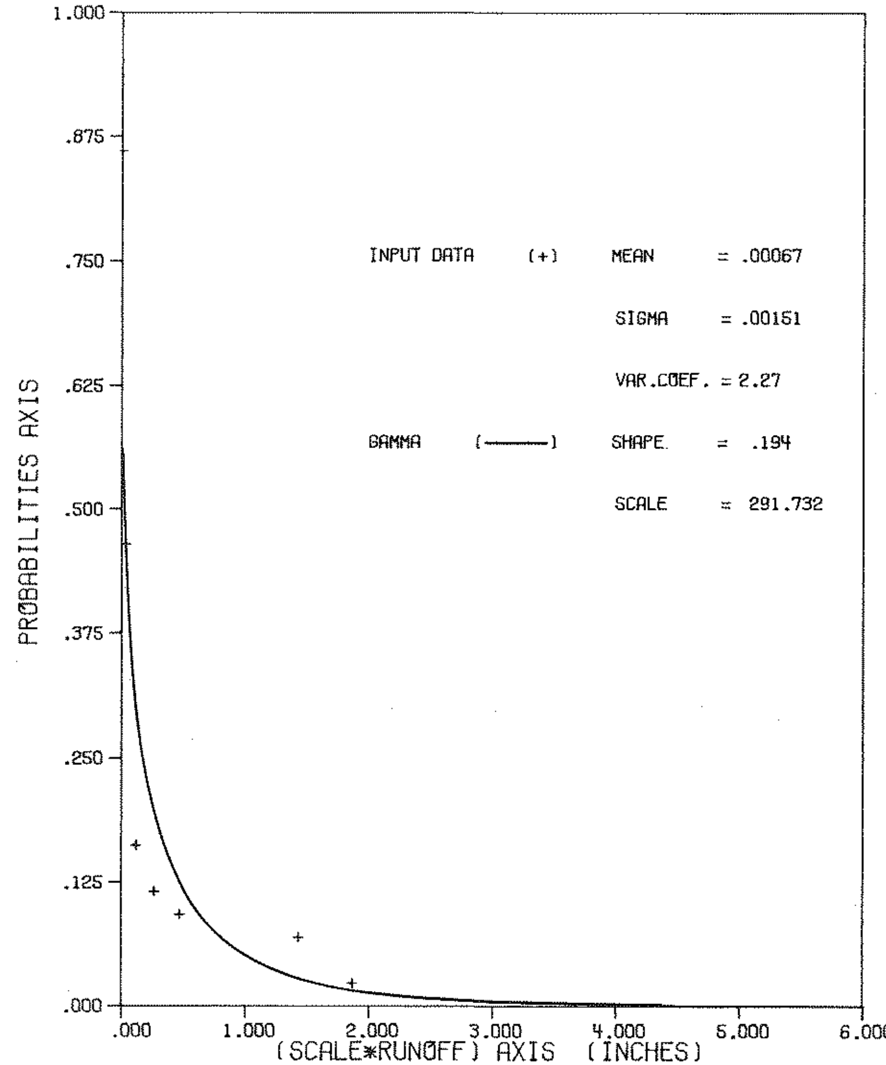

Figure 13 Distributions of Squared Deviations of Observed and Computed Runoff by Event (Option I)

Statistical distributions were used to evaluate the sensitivity of the model to the input parameters. The gamma distribution, $\Gamma(k,\lambda)$ was chosen for this purpose. The gamma distributions fitted to the observed and calculated runoff values along with the respective confidence intervals are shown in Figures 10 and 11. Also shown in the figures are the shape parameter k and the scale parameter λ which define the distribution. It is seen that, with very few exceptions the data fall within the 5% confidence band, and the gamma distribution represents reasonably well the distribution of the observed and calculated runoff values. A better fit would require a distribution with 3 or more parameters. However, it was felt that the two-parameter gamma distribution was adequate as the statistical analysis should not be more sophisticated than the model it attempts to evaluate.

The shape and scale coefficients of the fitted distributions are 13% and 11% larger, respectively, for the calculated values than for the observed runoff values. However, it appears from Figure 12, that both the empirical and the fitted distributions of observed and calculated runoff values are very close, and that in regard to the probability distributions of the runoff values by event the model is performing satisfactorily.

3.1.5.2 Maximum (Peak) Runoff per Event

The presentation of the empirical and fitted distributions of the maximum runoff per event is the same as for the total amount of runoff per event. Figures 14 and 15 show the empirical distributions and the gamma distributions fitted to the observed and calculated peak runoffs by event. The means of the observed and computed peaks are essentially the same but the standard deviation of the calculated peaks is almost 10% smaller than that of the observed peaks. As a result the coefficient of variation of the calculated peak is about 9% smaller than that of the observed peaks. The percent error in the standard deviation of the peaks is approximately twice that of the total amounts of runoff by event.

It can be observed that the gamma distribution underestimates the extreme (low and high) values, and overestimates the central values. A larger set of values would certainly give a better approximation than that obtained with 42 values. However this number of events is representative of a typical year in the Midwestern United States.

The shape and scale coefficients of the gamma distributions fitted to the calculated peaks are 13% and 11% larger, respectively, than those corresponding to the observed peaks. These percentage errors are exactly the same as those for the total amounts of runoff by event.

Figure 16 shows the distributions of the observed and calculated peaks, they are plotted making use of the scale factors shown in Figures 14 and 15, respectively. Figure 17 shows the distribution of the square of the deviations between the observed and the calculated peaks.

As a result it may be stated that the model tends to produce values such that the peak runoffs and the cumulative runoffs by event follow distributions which closely approximate those of the observed events, but with a slightly smaller spread in the calculated values than in the observed ones.

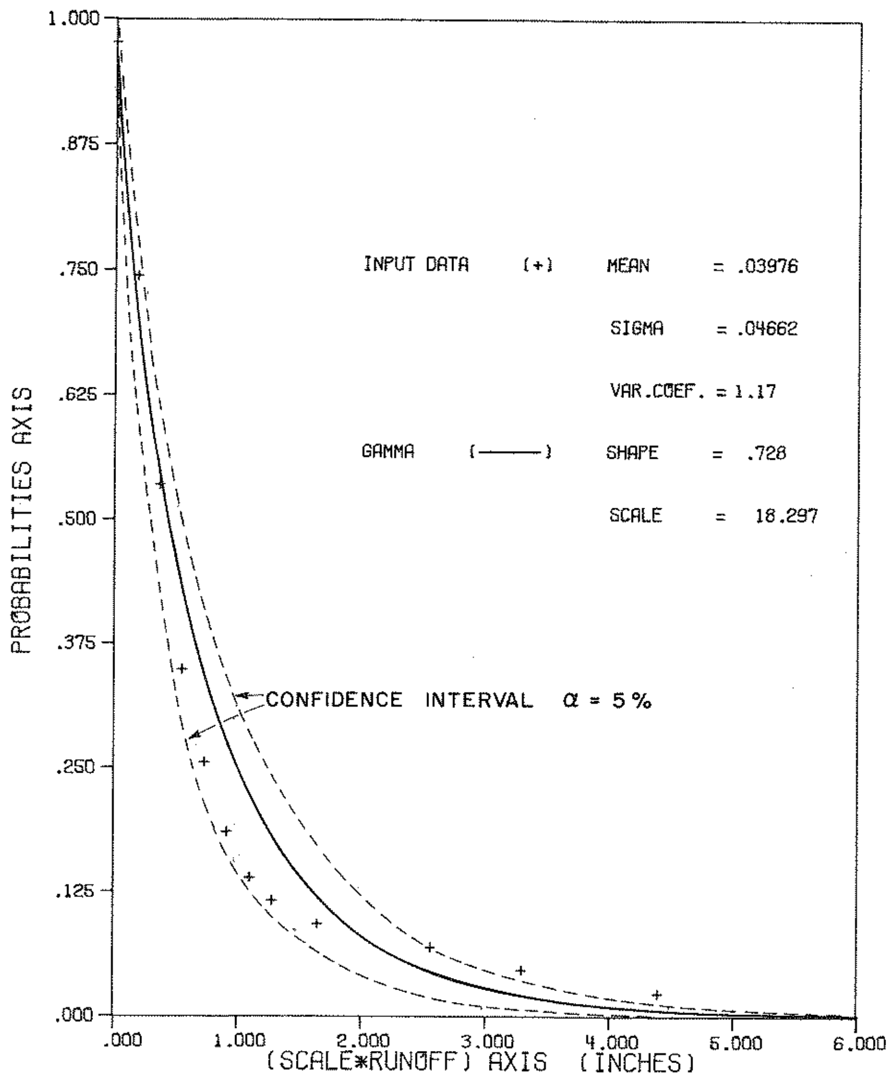

Figure 14 Distribution of Observed Peak Runoffs by Event (Option I)

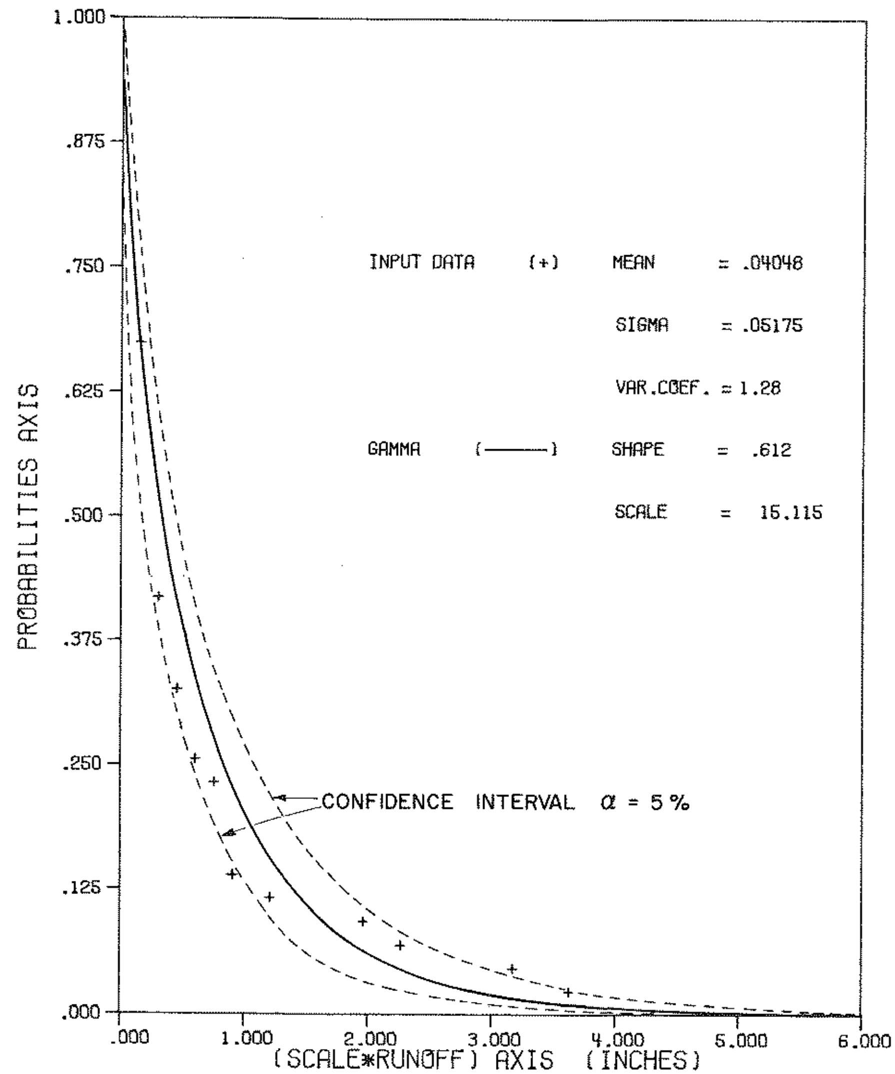

Figure 15 Distribution of Computed Peak Runoffs by Event (Option I)

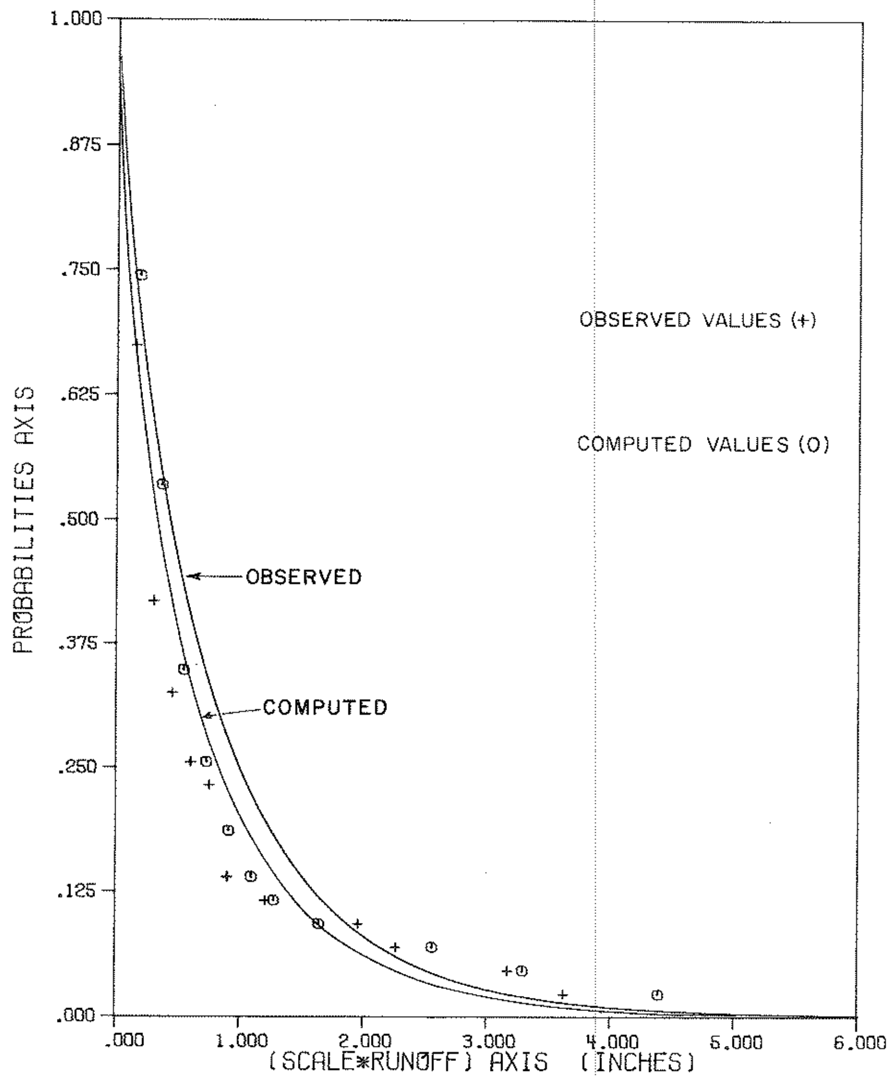

Figure 16 Distributions of Observed and Computed Peaks by Event (Option I)

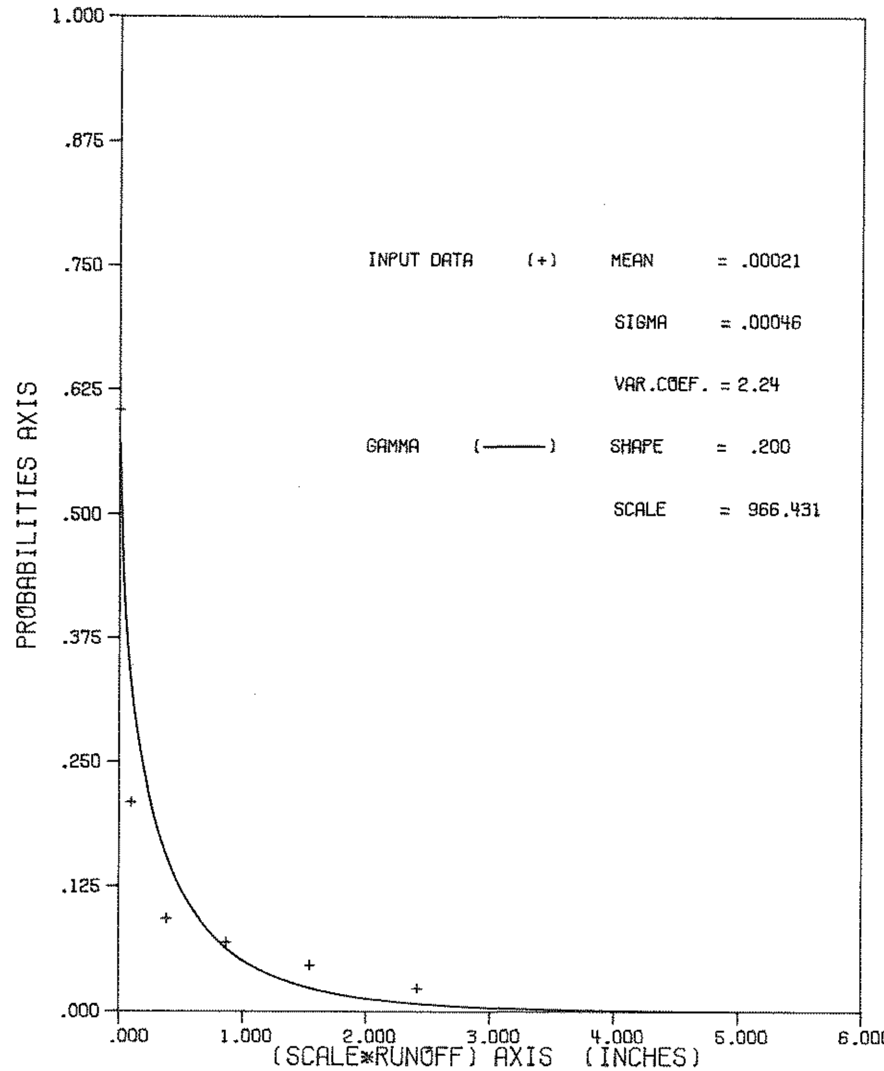

Figure 17 Distributions of Squared Deviations (Observed-Computed) of Peaks by Event (Option I)

3.1.6 Sensitivity Analysis by Modifying the Depression Storage "f_{max}"

In modifying the value of the composite runoff coefficient or of the rainfall, it is seen From Fig. 8 that a relative error of Y_R in the rainfall, with $Y_C = 0$ or conversely a relative error of Y_C in the composite runoff coefficient with $Y_R = 0$, produce errors in the runoff, Z_{RC} of the same order of magnitude. This is no longer the case when the value of f_{max} is modified around its calibration value. The results obtained for the number of events and for the total amount of runoff are shown in Table 3.

Gamma distributions were fitted to the total amounts of runoff by event, for f_{max} taking values 0.18, 0.21, and .25. These distributions are shown in Figures 18 through 20. The distribution corresponding to $f_{max} = 0.23$ is shown in Fig. 11. The superposition of these figures with Fig. 10 shows that all distributions fitted to the calculated runoff amounts by event fall within the upper confidence interval for the gamma distribution fitted to the observed runoffs by event. The parameters of the several distributions are listed in Table 3.

Figure 21 shows the distribution of the computed peak runoffs by event for $f_{max} = 0.18$, and may be compared to Fig. 15 which corresponds to $f_{max} = 0.23$ and Fig. 14 which shows the distribution of the observed peaks by event. The superposition of Figs. 14, 15 and 23 shows that the two distributions fitted to the calculated peaks fall within the upper confidence interval for the gamma distribution fitted to the observed peaks by event. The parameters of these distributions are listed in Table 3.

Table 3 Effect of Modifying the Maximum Depression Storage on the Total Runoff and Runoff by Event

PARAMETERS	OBSERVED VALUES	CALCULATED VALUES			
f_{max}	-	0.18	0.21	0.23	0.25
Total Runoff (225 days)	3.05	3.25	3.13	3.06	2.99
No. of Runoff Events	40	45	44	42	42
Mean Runoff by Event (in.)	.07262	.07267	.07114	.07357	.07167
Std. Deviation of Runoff by Event	.08892	.08478	.08480	.08482	.08539
Var. Coeff. of Run-off by Event	1.22	1.17	1.19	1.15	1.19
Shape Factor of Runoff by Event	0.667	0.735	0.704	0.752	0.704
Scale Factor of Runoff by Event	9.183	10.109	9.891	10.226	9.829
Mean Peak by Event (in.)	0.04048	0.0400		0.03976	
Std. Deviation of Peaks	0.05175	0.04786		0.04662	
Var. Coeff. of Peaks	1.28	1.20		1.17	
Shape Factor of Peaks	0.612	0.698		0.728	
Scale Factor of Peaks	15.115	17.460		18.297	

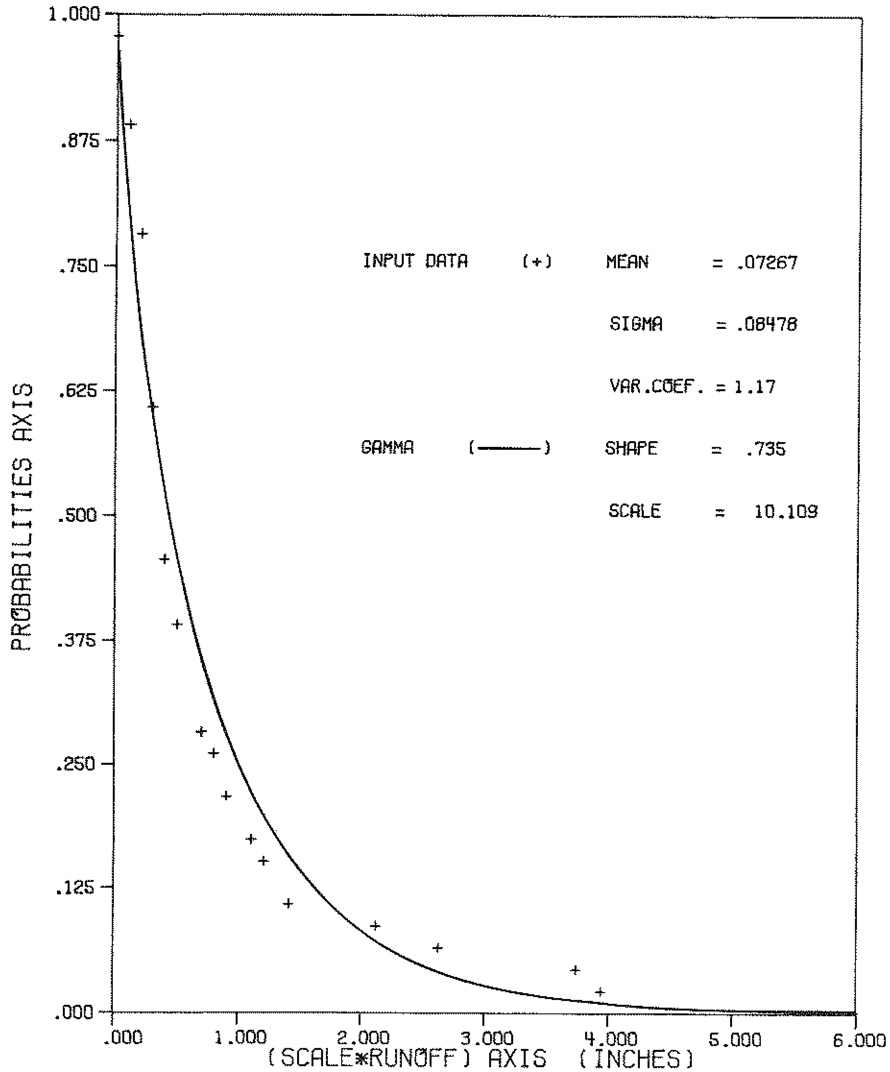

Figure 18 Distribution of Computed Amount of Runoff by Event for f_{max} = 0.18 (Option I)

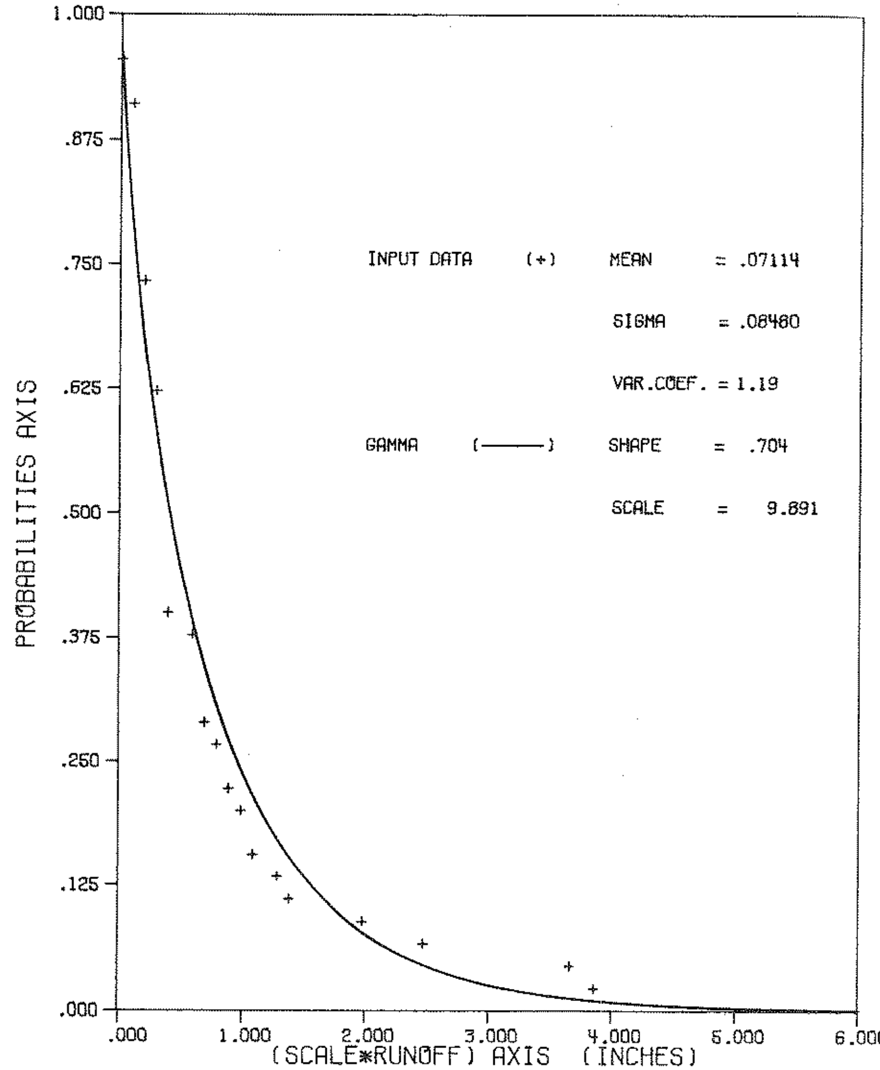

Figure 19 Distribution of Computed Amount of Runoff by Event for f_{max} = 0.21 (Option I)

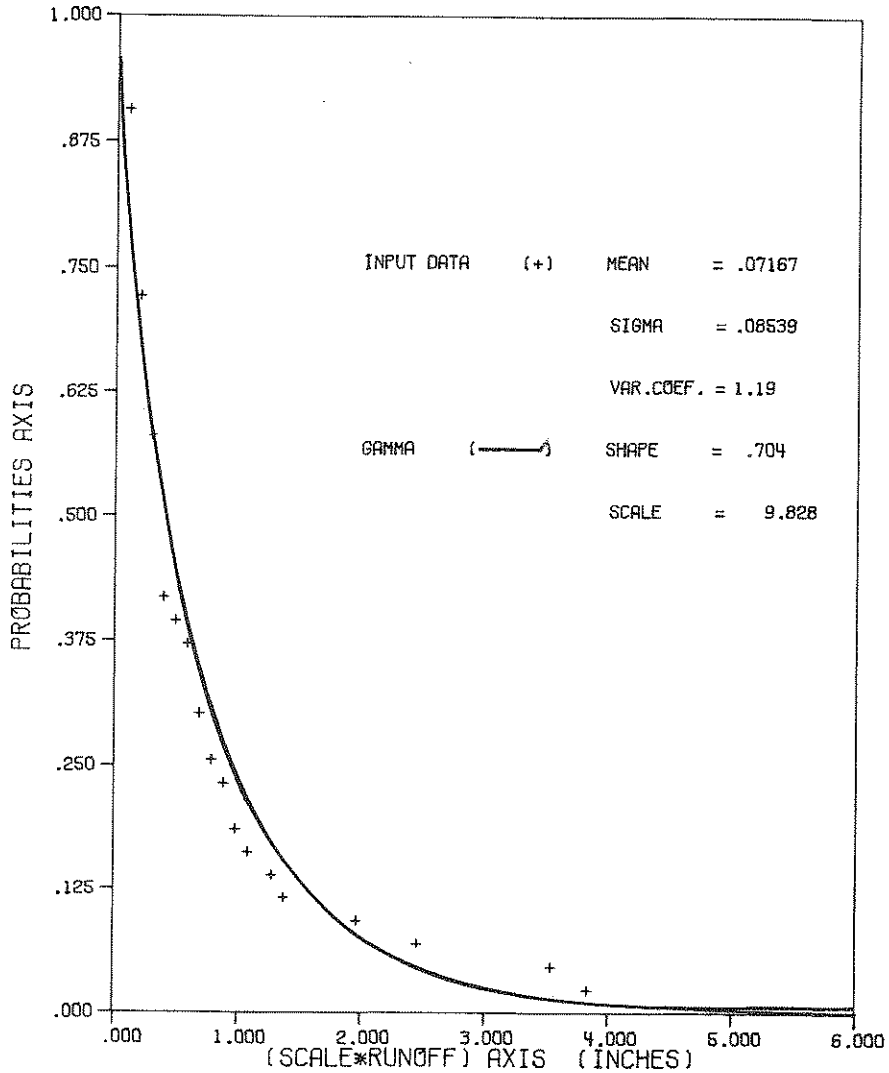

Figure 20 Distribution of Computed Amount of Runoff by Event for f_{max} = 0.25 (Option I)

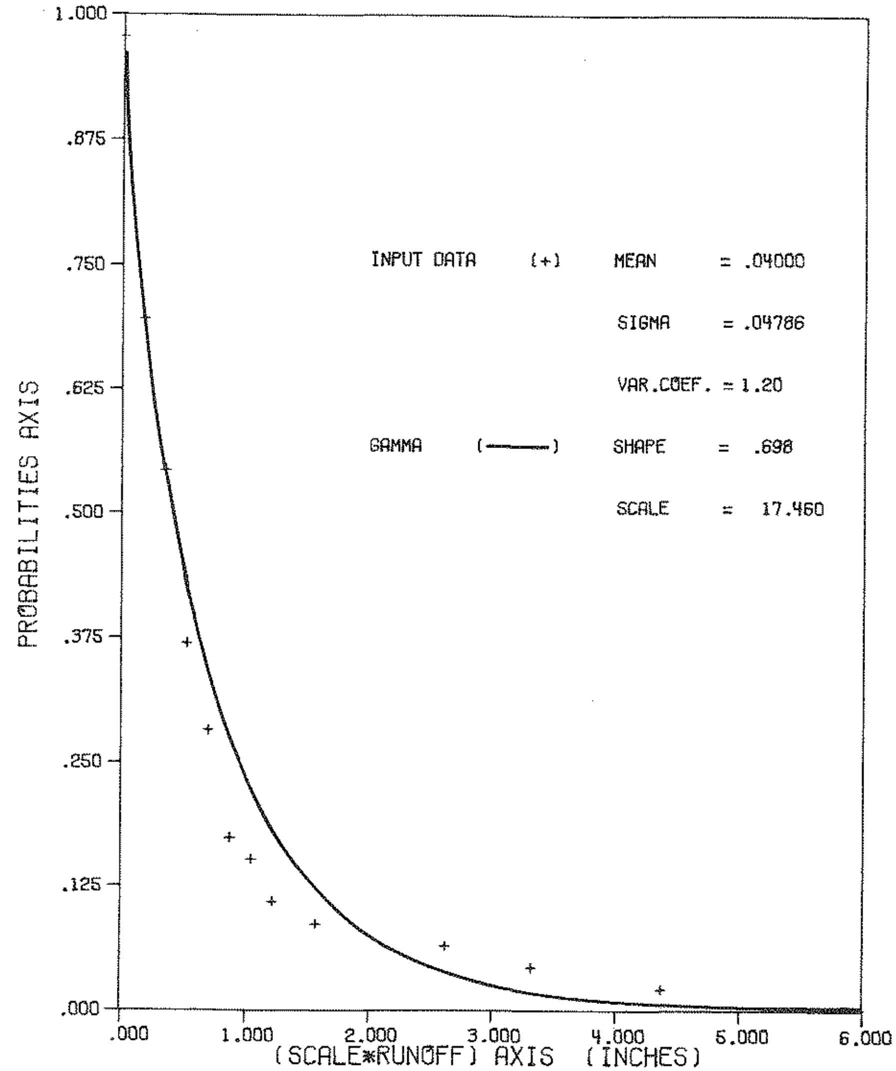

Figure 21 Distribution of Computed Peak Runoffs by Event for f_{max} = 0.18 (Option I)

Although all the used values of f_{max} appear to give comparable distributions of runoff amounts and peak runoffs by event, only the value of $f_{max} = 0.23$ gives acceptable values of the number of events and of the total amount of runoffs over the period of 225 days.

It appears that the total runoff over an extended period and the number of runoff events in that period can be used to select the correct value of f_{max}. The probability distribution of the amounts and peak runoffs by event make it possible to compare the distributions of the computed and observed values but do not provide a means of discriminating between the values of f_{max}.

3.1.7 Goodness-of-Fit and Confidence Intervals

The χ^2 and Kolmogorov-Smirnov tests were attempted with a significance level of 5% for the observed and computed total amount of and maximum (peak) runoff by event. All results lead to the conclusion that the hypothesized model (Gamma) is not to be rejected.

A confidence interval was computed and is shown in Figs. 10, 11, 14 and 15, with a significance level of 5%. The method used is first to transform the gamma distribution into a straight line, then to find a confidence interval for the slope of this line, assuming that this parameter is normally distributed. The second parameter is known and is equal to 1.

With a few exceptions the data are located within the confidence interval band.

3.1.8 Conclusions

The analysis of the composite runoff coefficient method (Urban Areas) of the STORM model shows:

- an easy calibration of the parameters;
- the major importance of the impervious surface runoff coefficient and the necessity to determine its value with an accuracy of about 10%. This can be done by taking a weighted average of the coefficients of the different kinds of impervious areas;
- a stable model around the calibration values of its parameters;
- a good simulation of the total amount and maximum (peak value) of runoff by event (as seen in Figures 12 and 16);
- an acceptable fit by a gamma distribution of the simulated total and maximum (peak) runoff by event.

3.2 Semi-Urban Area (Option II)

The STORM model treats the case of a semi-urban basin by considering the following equations from the set of equations given in Section 1.3:

(a) Equations (1), (2), (3) and (4) for the pervious areas,

(b) Equations (5), (6) and (7) for the impervious areas.

In the Upper Ross-Ade Watershed example a low value of $C_P = .08$ (Table 2) was found and the accuracy in C_I was seen to be a decisive one. But in Eq. (6a) if C_I is assumed to be equal to zero, the composite runoff coefficient has to be multiplied by (1 + .38) to reach its correct value. Thus, the influence of the pervious areas on the total amount of runoff is seen to be 38%. It is not negligible, even though this fraction is not large enough to consider the whole area as a rural one as seen in Section 2.

The procedure making use of Equations (1), (2), (3) and (4) in the determination of the runoff from a rural area is more sophisticated than that used in the determination of the runoff in an urban area. In addition, there is no single lumped parameter representing the rainfall-runoff phenomenon, since the rainfall, the initial abstraction and the soil moisture storage are coupled in a nonlinear way to determine the runoff. The behavior of the total amount of runoff is thus analyzed as a function of each parameter considered sequentially.

As in Section 3.1, where a sensitivity analysis was developed before the model calibration, the same method is followed here in order to determine the decisive parameters.

3.2.1 Sensitivity Analysis

Each parameter is assumed to take some possible values around its calibration value and the behavior of the total amount of runoff is observed. The discussion in the following sections refer to the example of 1970 data for the Upper Ross-Ade Watershed. The effects of errors in the pan evaporation, soil moisture retention, abstraction capacity, infiltration and percolation rates on the total yearly runoff are discussed in the following sections.

3.2.1.1 Pan Evaporation

Figure 22 shows the effect of a relative error in the pan evaporation on the runoff. This effect is rather slight as large relative errors in the pan evaporation are not to be expected.

3.2.1.2 Maximum and Starting Soil Moisture Retention

Figure 23 shows the influence of relative errors in the maximum and in the starting values of the soil moisture retention on the total yearly runoff.

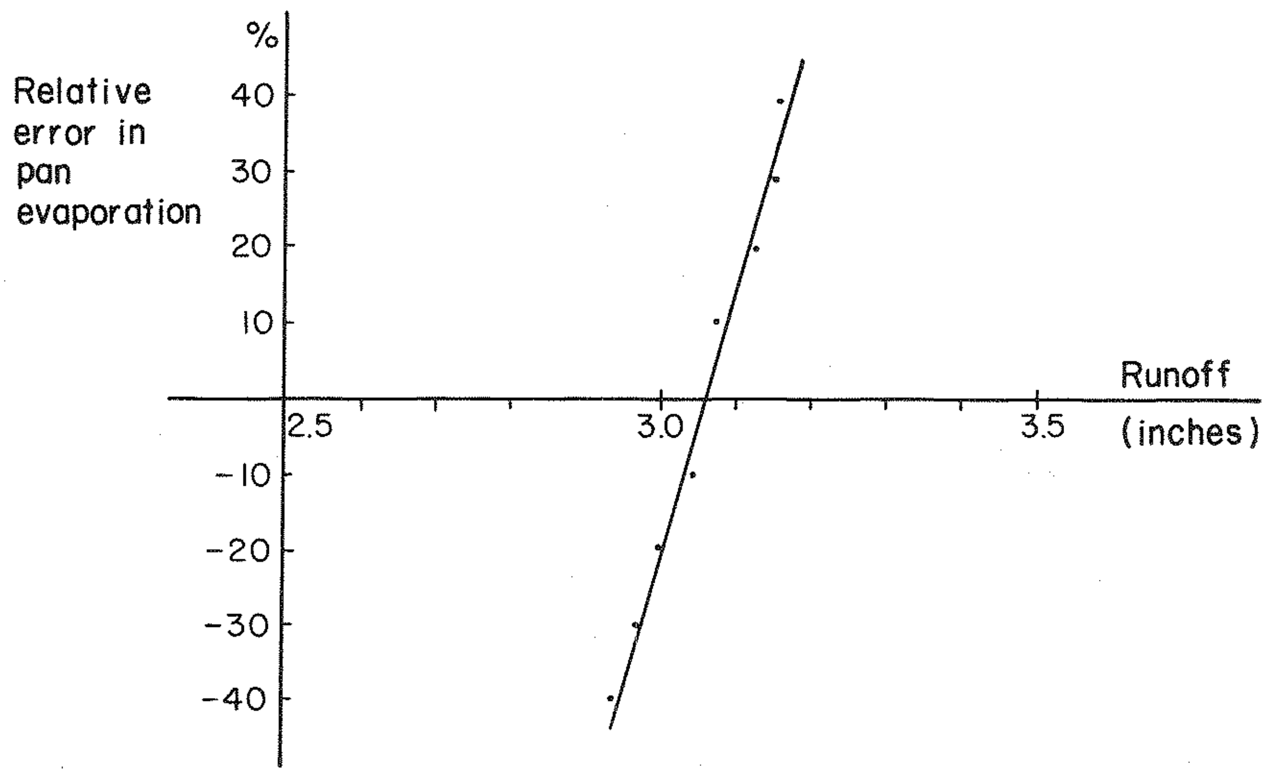

Figure 22 Effect of Relative Errors in the Pan Evaporation on the Total Yearly Runoff (Option II)

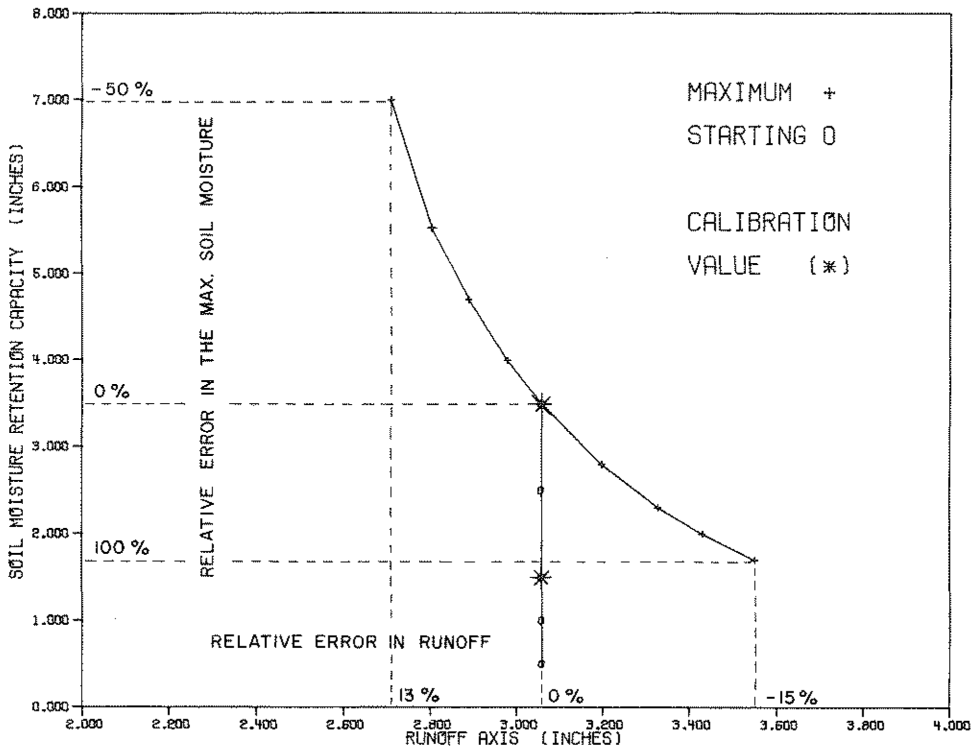

Figure 23 Effect of Variations of the Maximum and Starting Values of the Soil Moisture Retention Capacity on the Total Runoff

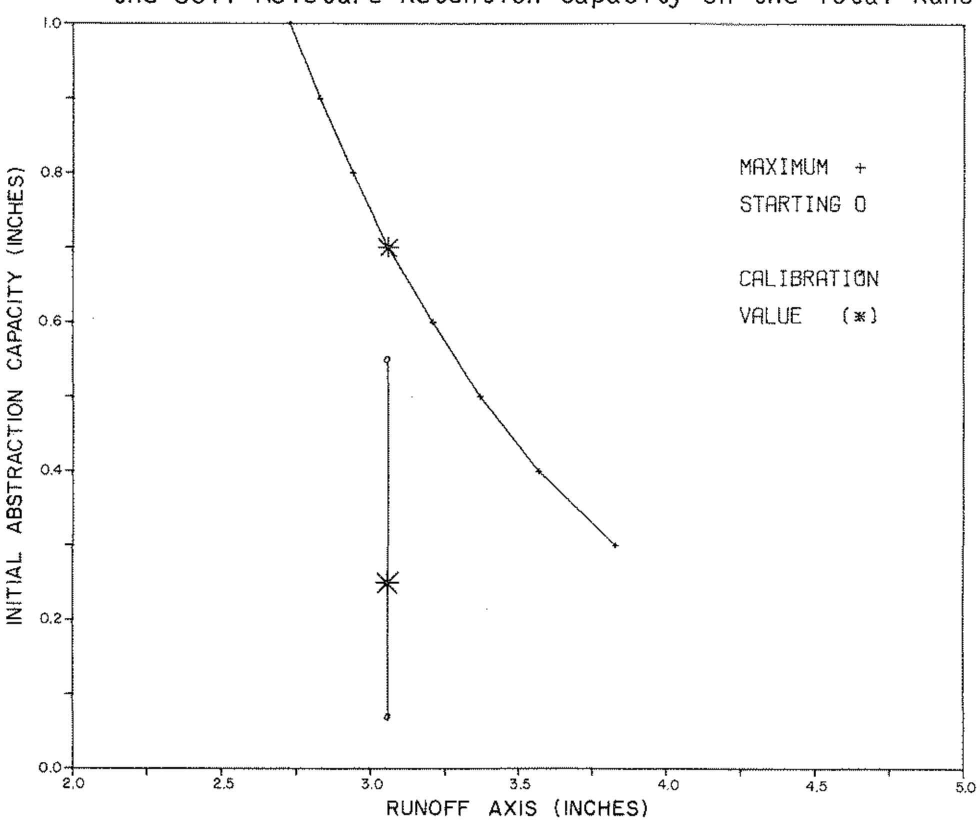

Figure 24 Effect of Variations of the Maximum and Starting Values of the Initial Abstraction Capacity on the Total Runoff

The maximum soil moisture retention characterizes the soil at each step of the calculation process and practically it is seen to determine the amount of water available for runoff. Therefore this parameter is decisive.

The starting soil moisture retention relates only to the first step of the calculation and is seen to have no measurable influence on the amount of yearly runoff.

3.2.1.3 Maximum and Starting Initial Abstraction Capacity

Figure 24 shows the effect of relative errors in the maximum and in the starting values of the initial abstraction capacity on the total yearly runoff.

Since there is a relationship between the soil moisture and the initial abstraction capacity, similar effects as for the soil moisture retention are observed. The starting value of the initial abstraction has no measurable influence on the total yearly runoff, whereas the effect of the maximum value is a decisive one. The Soil Conservation Service [3] found that the following relation gives usually good results:

$$IA = 0.2 * S \qquad (16)$$

where: S = soil moisture retention

IA = initial abstraction capacity

3.2.1.4 Maximum Infiltration and Soil Percolation Rates

Figure 25 shows the effect of variations in the maximum infiltration and maximum percolation rates on the total yearly runoff. It is seen that when the values of the maximum infiltration and of the soil percolation rates are larger than about 0.2 in/hr, the influence of these two parameters on the runoff is negligible.

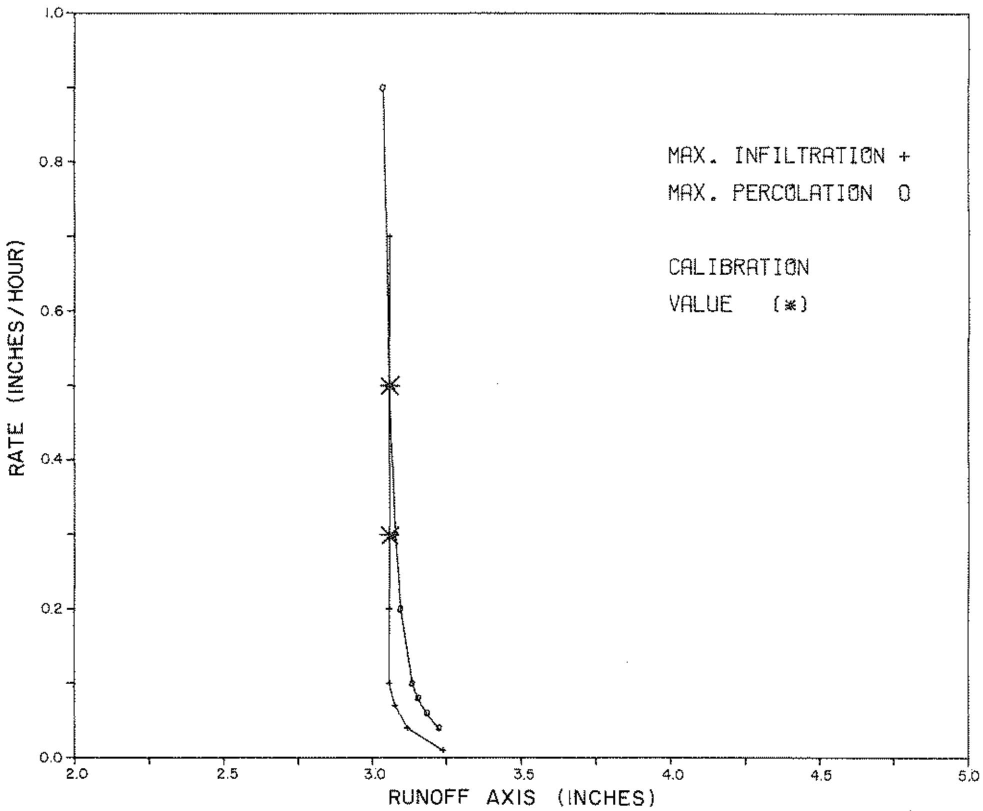

Figure 25 Effect of Variations of the Maximum Infiltration and Percolation Rates on the Total Runoff

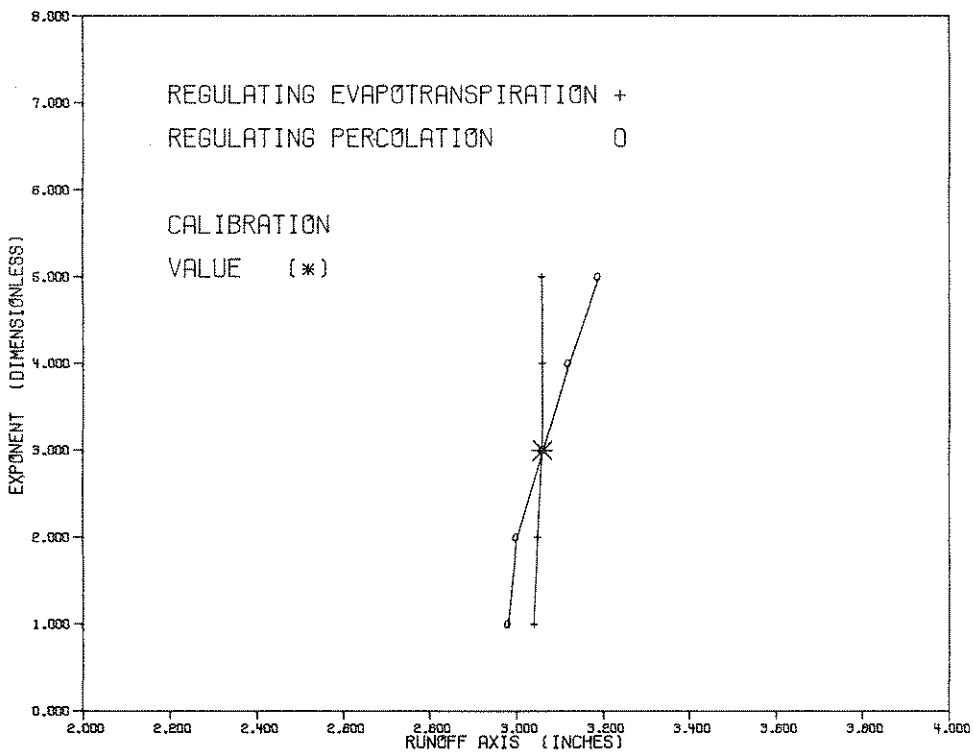

Figure 26 Effect of Variations of the Exponents Regulating v and p Regulating the Evapotranspiration and the Percolation on the Total Runoff

However, if under the upper soil horizon there is a stratum formed by clayey particles, then the values of these two parameters become low and the runoff increases significantly.

3.2.1.5 Exponents Regulating the Evapotranspiration and the Percolation

Figure 26 shows how the total yearly runoff is affected by variations in the exponents v, and p regulating the evaporation and the percolation, respectively. After some experimentation, a small variation of the runoff was observed after modifying these two parameters between 1 and 5, with the maximum soil moisture retention, the pan evaporation and the percolation rates at their correct calibration values.

3.2.1.6 Comments on the Magnitude of the Parameters

In practice it is not unusual to estimate a parameter with a relative error ranging between -50% and +100%. For the most sensitive parameter, the soil moisture retention capacity, this leads to a relative error in the total amount of runoff ranging between 13% and -15% respectively, as shown in Fig. 23.

The other parameters depend to some extent on the soil moisture retention capacity or are calibration values.

3.2.2 Calibration

3.2.2.1 Data

From the soil map (Fig. 27 and Table 4) and from soil sample values, the following data are obtained:

max. soil moisture retention capacity	≃ 3.5 inches
max. soil infiltration rate	≃ 0.3-0.6 inches/hour
max. percolation rate	≃ 0.5-0.6 inches/hour
infiltration rate	≃ 0.15 inches/hour

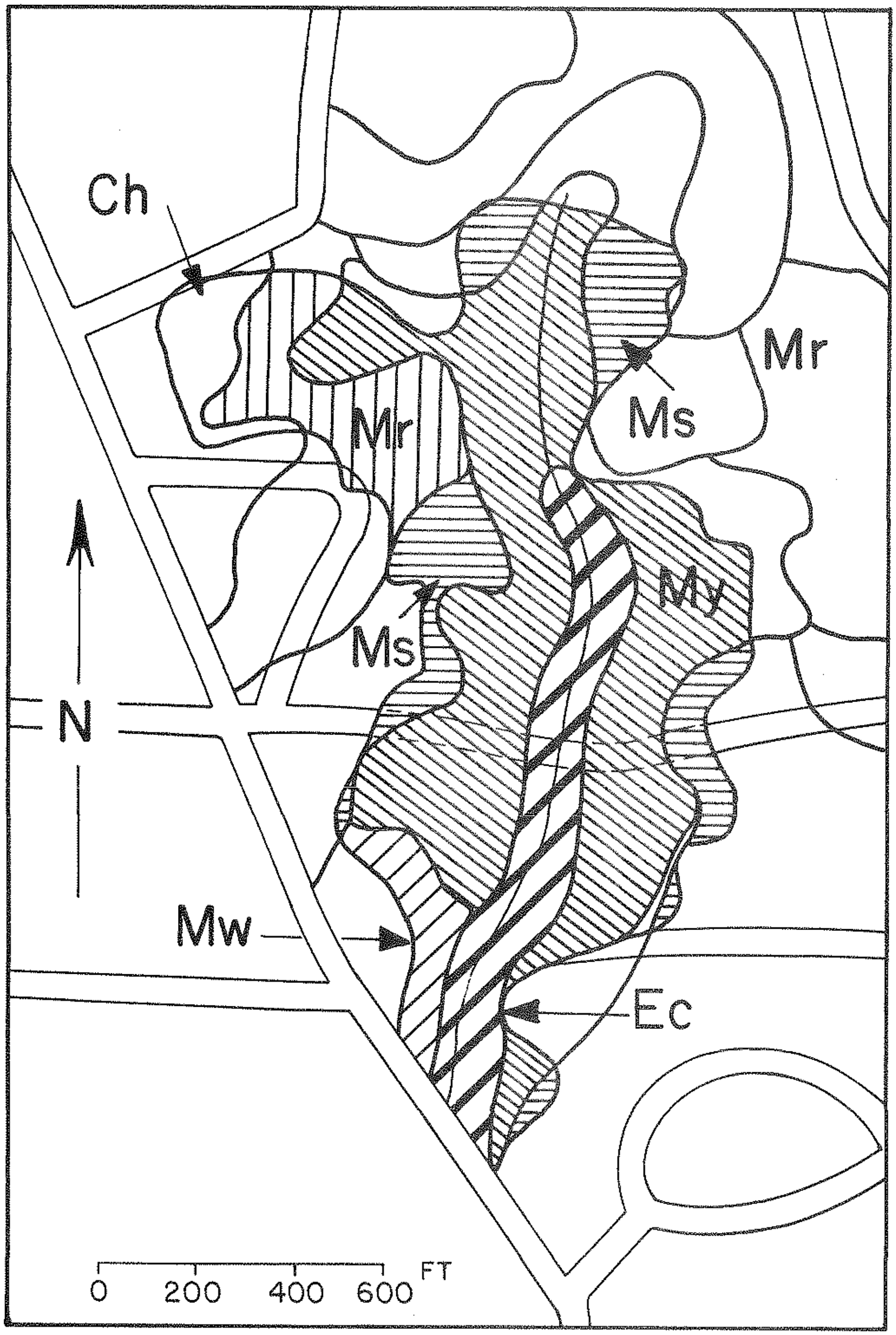

Figure 27 Soil Map - Upper Ross-Ade Watershed

Table 4 Principal Soils in the Upper Ross-Ade Watershed

(a) Miami Silt Loam, 3 to 8 percent slope, Mr: the depth to the calcareous till ranges from 24 to 42 inches. About 7 percent of the watershed area contains this soil.

(b) Miami Silt Loam, 3 to 8 percent slopes, Ms: the surface layer is silty clay loam to heavy silt loam. Thirteen percent of the watershed area contains this type of soil.

(c) Miami Silt Loam, 12 to 35 percent slopes, eroded, Mw: in severely eroded areas the top layer is silty clay loam. Five percent of the soil in the watershed is of this type.

(d) Miami Silt Loam, 12 to 35 percent slopes, Mv: this soil is like Miami Silt Loam, 3 to 8 percent slopes, except that the slope is steeper. About 49 percent of the watershed contains this type of soil.

(e) Eel Silt Loam, 0 to 3 percent slopes, Ec: this is the dominant soil on the bottom lands of the streams. The surface soil, to depths of 6 to 8 inches is a grayish brown silt loam. There is about 16 percent of the area of the watershed containing this type of soil.

(f) Crosby Silt Loam, 0 to 3 percent slopes, Ch: this is an imperfectly drained soil. About 7 percent of the watershed is of this type of soil.

3.2.2.2 Decisive Parameters

The value of the maximum soil moisture retention capacity of the soil cover at the Upper Ross-Ade Watershed used by Hossain et al. [4] in a study of the infiltration in this basin was 3.5 inches. Using relation (16) $IA = 0.2 * S$, the value of the maximum initial abstraction capacity is 0.7 inches.

3.2.2.3 Less Decisive Parameters

As the infiltration rate has a low value of .15 in/hr the lower limit is considered for the maximum soil infiltration rate and the maximum percolation rate:

maximum soil infiltration rate	.3 in/hr
maximum percolation rate	.5 in/hr

Measured values for the pan evaporation rate are considered of acceptable accuracy.

3.2.2.4 Exponents

The actual calibration of the model under Option II is performed over the two parameters, the exponent v regulating evapotranspiration, and the exponent p regulating percolation. They are calibrated so as to adjust the simulated total yearly (225 days) runoff and the simulated total yearly number of runoff events, to the corresponding observed values.

3.2.3 Results (Final Calibration)

The final calibration values of the model parameters for Option II are grouped in Table 2. Probability distributions of the calculated amounts of runoff by event and of the calculated peak runoffs by event were plotted and gamma distributions $\Gamma(k,\lambda)$ were fitted to these data in the same manner as explained in the discussion of the "urban area" option. The distribution of the computed total amount of runoff by event is shown in Fig. 28. The calculated mean runoff by event is very close to the observed mean, but the standard deviation is almost 48% larger, resulting in a much larger coefficient of variation. Superposition of Fig. 28 and Fig. 10 (which shows the distribution of the observed runoff amounts by event) shows that the gamma distribution fitted to the calculated amounts (Fig. 28) falls above the 5% confidence interval of the distribution fitted to the observed amounts. The distribution fitted to the square of the deviations (observed-calculated) of the total amounts of runoff by event is shown in Fig. 29. Comparison with Fig. 13 (for Option I, urban area) shows that scale factor for Fig. 29 (Option II - urban/rural) is approximately 10 times smaller, resulting in a larger probability of error in Option II for comparable runoff amounts.

Figure 30 shows the distribution of the calculated peak runoffs by event and the fitted gamma distribution. Comparison with Fig. 14 for the observed peaks shows that the calculated mean peak is about 9% smaller than the observed mean peak, and the standard deviation of the calculated peak is about 9% larger than that of the observed peaks. Superposition of Figs. 14 and 30 shows that the distribution fitted to the computed peaks almost coincides with the lower confidence limit for the distribution of the observed peaks. Fig. 31 shows the distribution of the squared deviations (observed-computed) of the peaks by event. Comparison with Fig. 17 (for Option I, urban area) shows that the scale factor is approximately 8.5 times smaller indicating a larger probability of error in Option II for comparable runoff peaks.

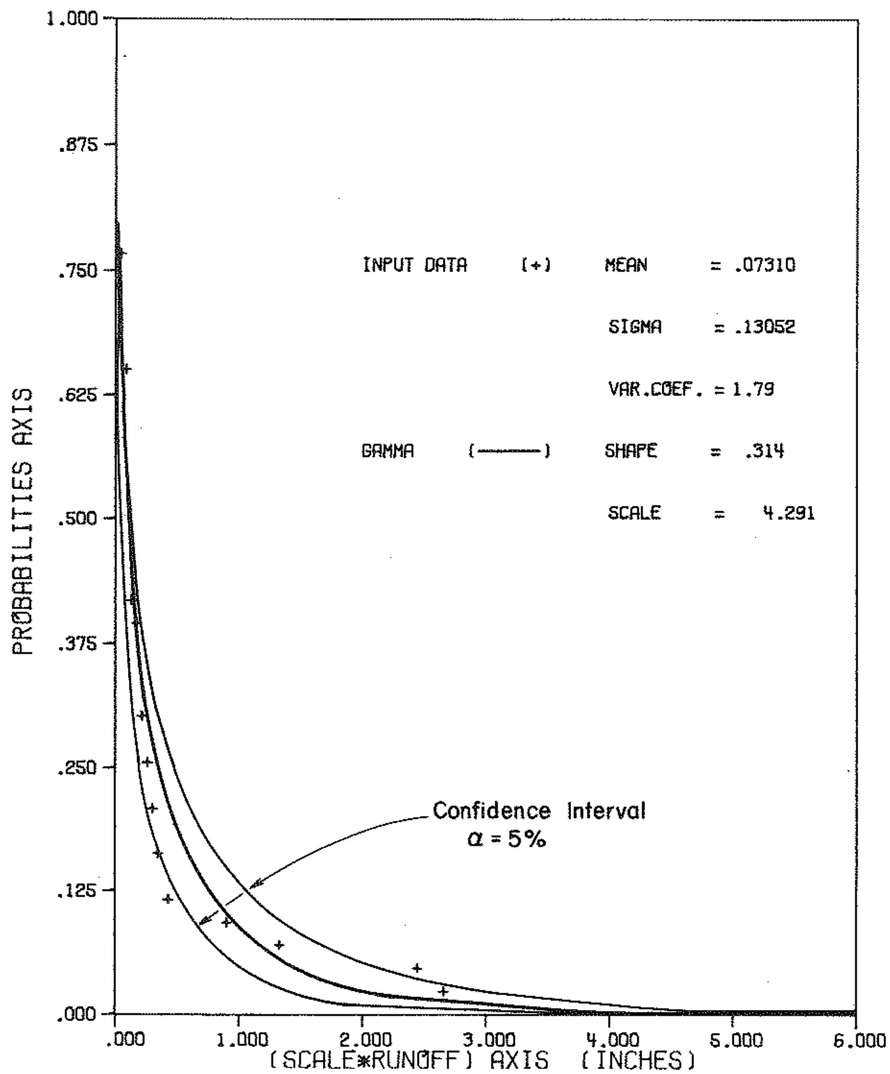

Figure 28 Distribution of the Computed Amounts of Runoff by Event (Option II)

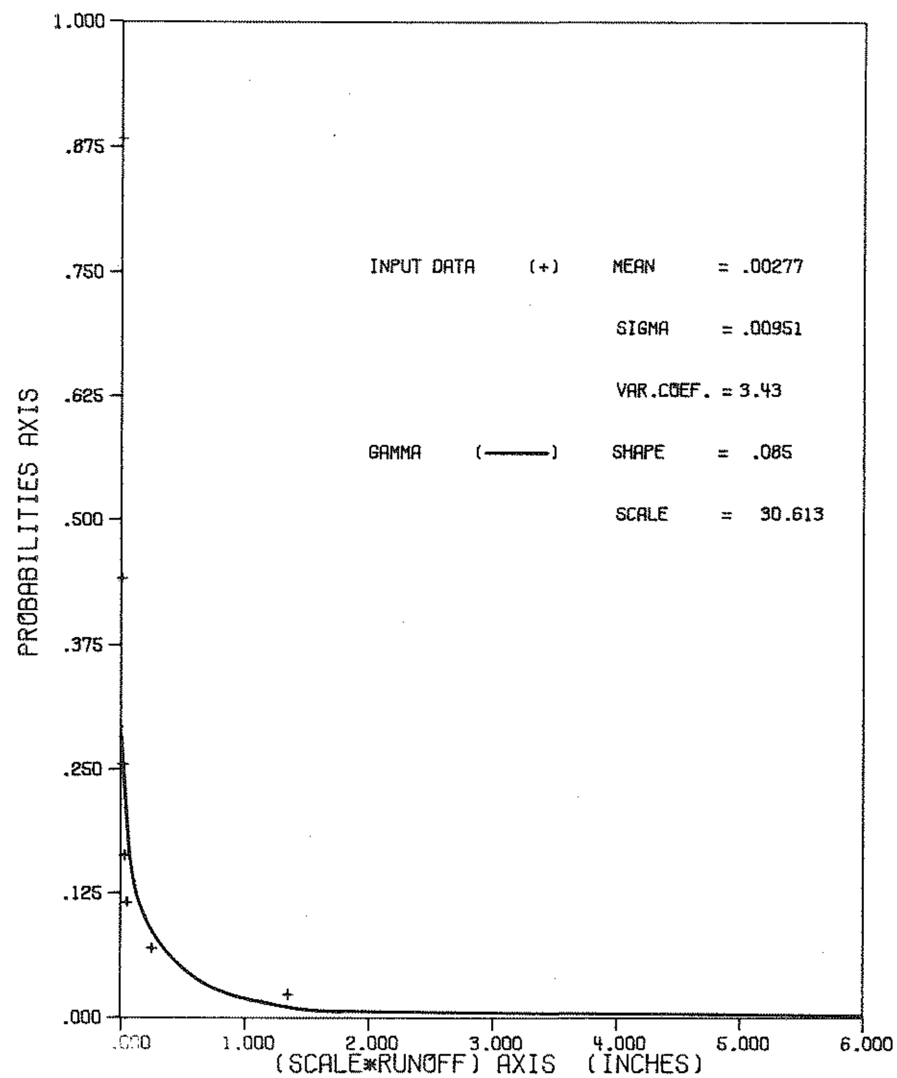

Figure 29 Distribution of Squared Deviations (Observed-Computed) of the Amounts of Runoff by Event (Option II)

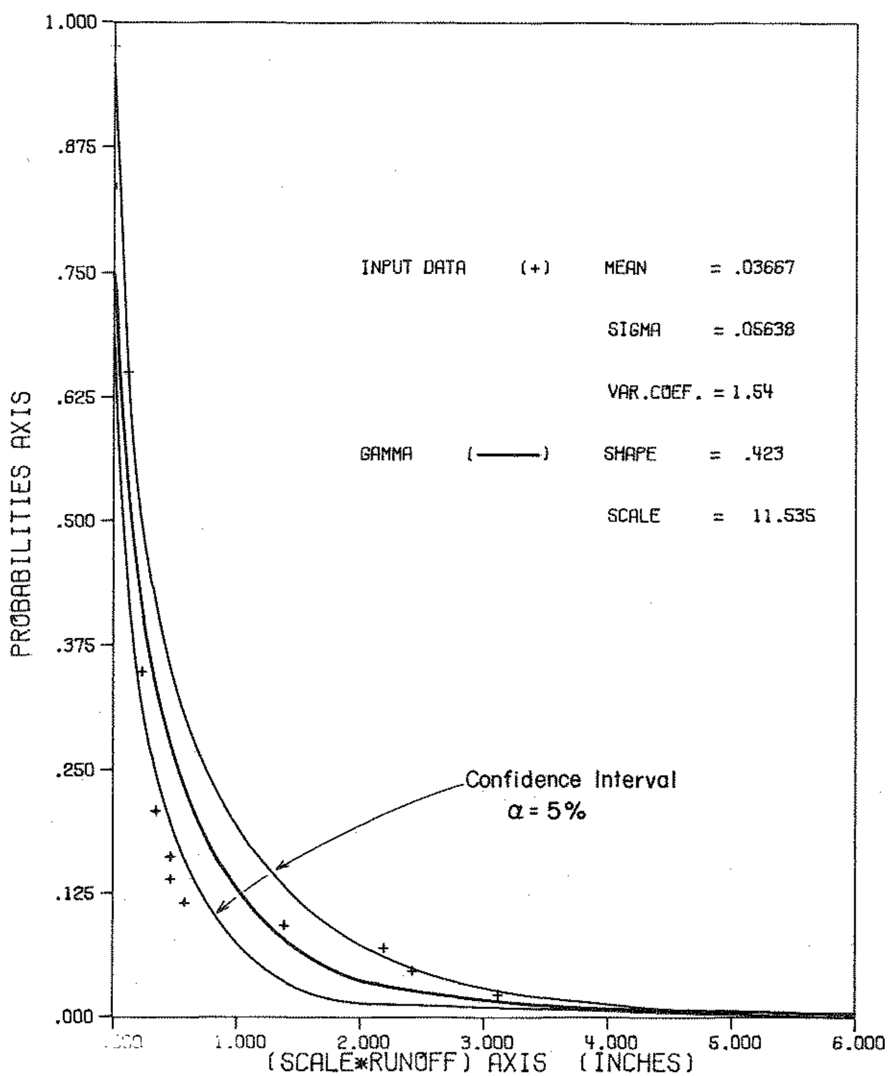

Figure 30 Distribution of Computed Peaks by Event (Option II)

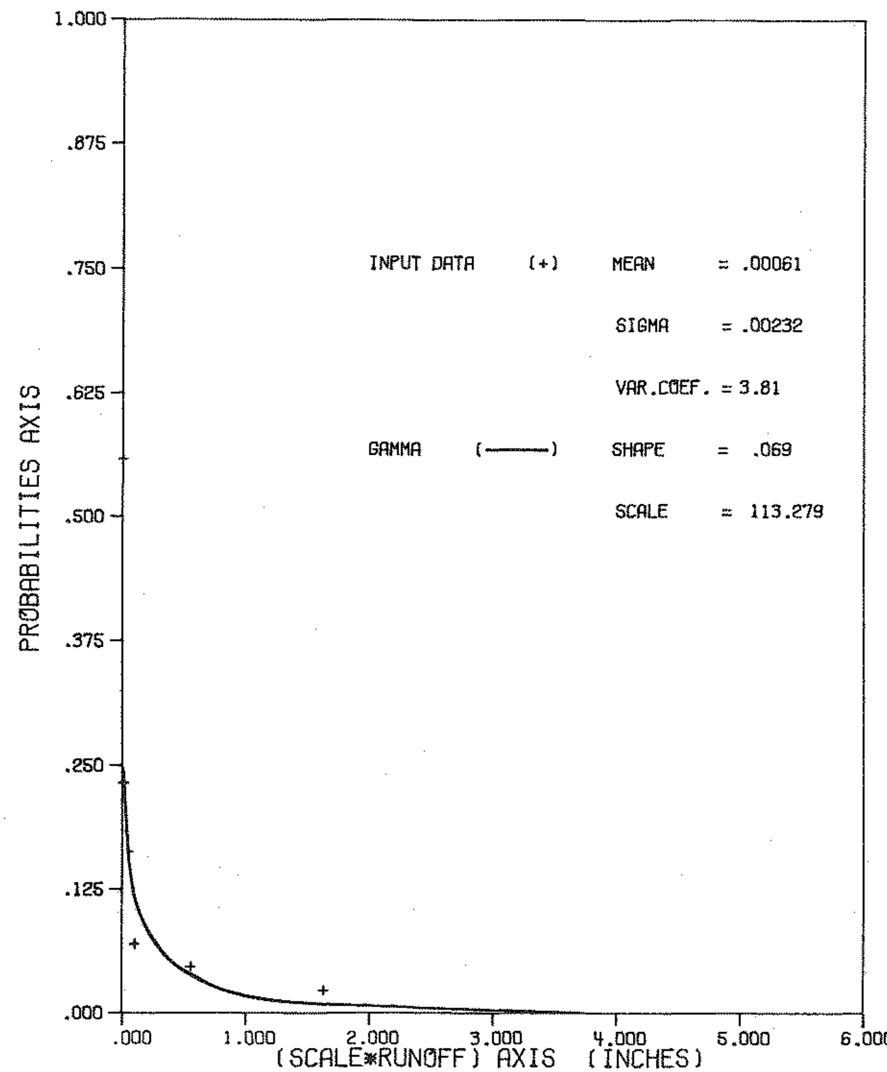

Figure 31 Distribution of the Squared Deviations (Observed-Computed) Peaks by Event (Option II)

3.2.4 Goodness-of-Fit and Confidence Intervals

The goodness-of-fit tests and the confidence intervals (see Figs. 28 and 29) were calculated for Option II. The results, however, were not as good as for Option I. Table 5 gives a summary of the statistics for both options and shows the superiority of Option I for the example analyzed. Nevertheless Option II gives an acceptable simulation considering the large imperviousness (38%) of this semi-urban area. The distribution of the computed and observed distributions of the runoff amounts and peak runoff amounts and peak runoffs by event are shown in Figs. 32 and 33, respectively.

3.2.5 Conclusions

The analysis of the combined procedure of the composite runoff coefficient method for the impervious areas and of the SCS method for the pervious areas, considered together on the same semi-urban watershed show:

- an easy calibration of the parameters;
- the major importance of the maximum soil moisture retention capacity parameter and the necessity to determine its value in the laboratory and with a great accuracy;
- the help provided by a soil map;
- a stable model around the calibration values of its parameters;
- a reasonably good simulation (total and maximum (peak) amount of runoff by event) considering the large imperviousness (38%) of this semi-urban area (see Figures 32 and 33);
- a relatively acceptable fit by a Gamma distribution for the computed total and maximum (peak) amounts of runoff by event.

Table 5 Summary of Statistics

PARAMETERS	OBSERVED VALUES	CALCULATED VALUES	
		Urban Option I	Urban/Rural Option II
Total Runoff (in) (225 days)	3.05	3.06	3.06
No. of Runoff Events	40	42	42
Mean Runoff by Event (in)	0.07262	0.07357	0.07310
error %		1.3	0.7
Std. Dev. Runoff by Event (in)	0.08892	0.08482	0.13052
error %		-4.6	47.8
Coeff. Var. Runoff by Event	1.22	1.15	1.79
error %		-5.7	46.7
Shape Fact. Runoff by Event	0.667	0.752	0.314
error %		12.7	-52.9
Scale Fact. Runoff by Event	9.183	10.226	4.291
error %		11.4	-53.3
Mean Peaks by Event (in)	0.04048	0.03976	0.03667
error %		-1.8	-9.4
Std. Dev. Peaks by Event (in)	0.05175	0.04662	0.05638
error %		-9.9	8.9
Coeff. Var. Peaks by Event	1.28	1.17	1.54
error %		-8.6	20.3
Shape Factor of Peaks	0.612	0.728	0.423
error %		19.0	-30.9
Scale Factor of Peaks	15.115	18.297	11.535
error %		21.1	-23.7

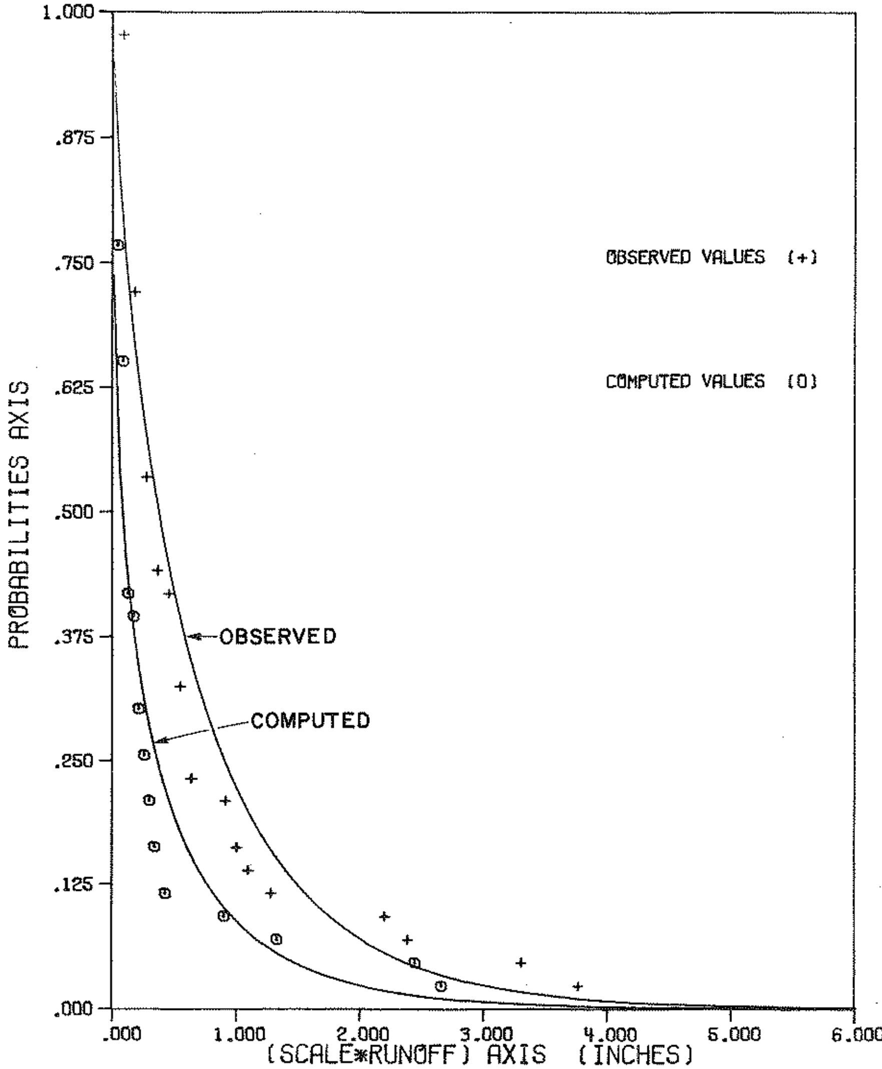

Figure 32 Distributions of Observed and Computed Amounts of Runoff by Event (Option II)

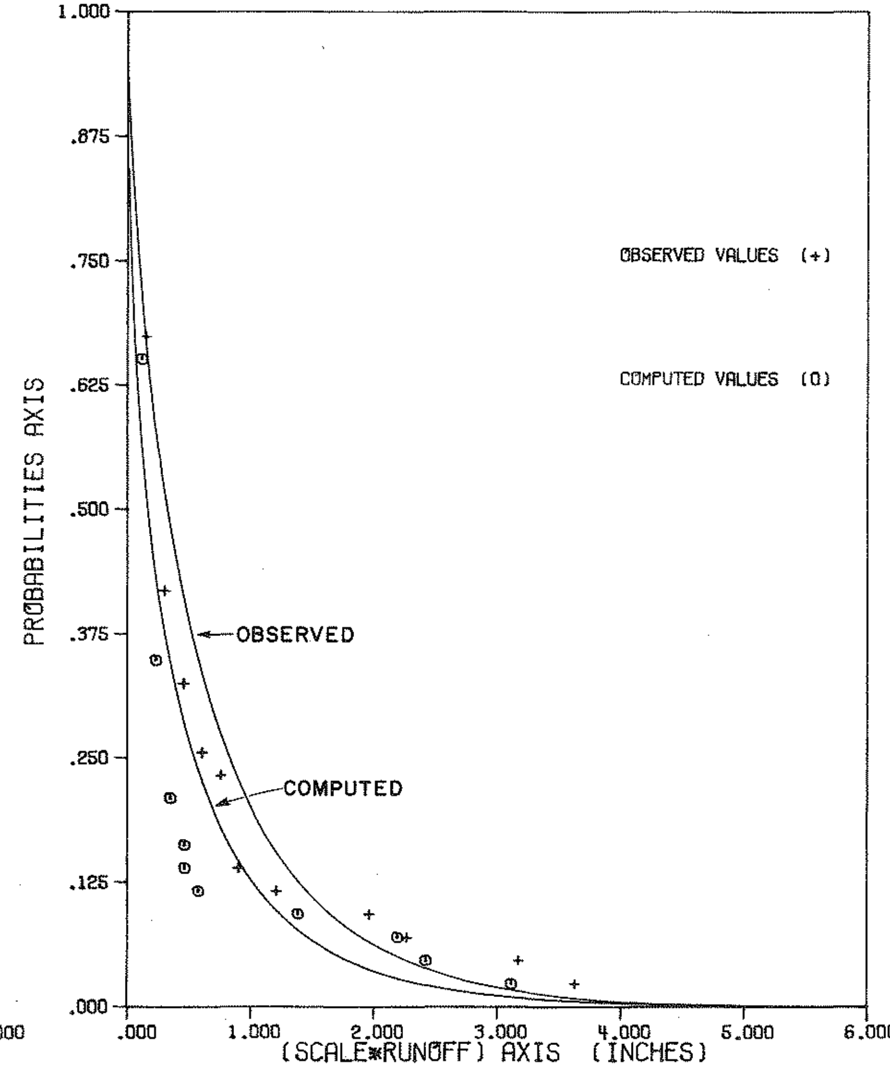

Figure 33 Distributions of Observed and Computed Peaks by Event (Option II)

CHAPTER 4

FINAL CONCLUSIONS

Since this study was based on data from the Upper Ross-Ade Watershed, the quantitative results obtained here should not be thoughtlessly transferred to other basins, as each particular basin has its own peculiarities. Nevertheless the methodology developed to calibrate the different options* involved in the continuous runoff simulation model STORM and to analyse its sensitivity is transferable to other basins.

In each case the following considerations remain true:

- In semi-urban areas the utilization of the two analyzed options is necessary to improve the confidence in the results;
- For 38% and probably lower imperviousness, the results provided by the composite runoff coefficient method (Option I) seem better than those provided by Option II;
- In Option I the impervious coefficient C_I is a decisive parameter and its determination requires a great accuracy;
- In Option II the decisive parameter is the maximum soil moisture retention capacity. Its determination requires an analysis in the laboratory;

**Option I :* *urban area, composite runoff coefficient method;*

Option II: *semi-urban area, composite runoff coefficient method for the impervious areas and SGS method for the pervious areas.*

- All other parameters in Option II have to be measured with care or approximated with the help of soil and topographic maps and to some degree by engineering judgement;
- The simulation results are good and give confident answers about the total amount of runoff by event and about the peak runoff values per event. Some information is provided about the actual hydrograph ordinates but requires some caution.

REFERENCES

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2. Abbott, J., "Guidelines for Calibration and Application of the STORM Model," The Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, California, Training Document No. 8, December 1977.

3. Mockus, Victor, et al., U.S. Soil Conservation Service," National Engineering Handbook, Section 4, Hydrology," August 1972.

4. Hossain, A., Delleur, J. W., and Rao, R. A., "Evaporation, Infiltration and Rainfall-Runoff Processes in Urban Watersheds," Purdue University Water Resources Research Center, Technical Report No. 41, 1974.

APPENDIX A

A.1 Derivation of Equations 9, 10, 11, 12 and 13

Equation (6) is rewritten for the case of a single land use. Capital symbols are used to designate exact quantities, lower case symbols are used for approximate quantities.

$$C = C_p + (C_I - C_p)F \tag{A-1}$$

$$c = c_p + (c_I - c_p)f \tag{A-2}$$

(A-1) can be rewritten as

$$(c + \Delta c) = c_p + \Delta c_p + (c_I + \Delta c_I - c_p - \Delta c_p)(f + \Delta f)$$

or expanding

$$c + \Delta c = c_p + \Delta c_p + c_I f + c_I \Delta f + \Delta c_I \Delta f + \Delta c_I f - c_p f - c_p \Delta f - \Delta c_p f - c_p \Delta f$$

and making use of (A-2)

$$\Delta c = \Delta c_p + c_I \Delta f + \Delta c_I \Delta f + \Delta c_I f - c_p \Delta f - \Delta c_p f - \Delta c_p \Delta f$$

or

$$\frac{\Delta c}{c} = \frac{\Delta c_p}{c_p}\frac{c_p}{c} + \frac{\Delta f}{f}\frac{f}{c}c_I + \frac{\Delta c_I}{c_I}\frac{\Delta f}{f}\frac{c_I f}{c} + \frac{\Delta c_I}{c}\frac{c_I f}{c} - \frac{f}{f}\frac{fc_p}{c}$$

$$- \frac{\Delta c_p}{c_p}\frac{c_p}{c}f - \frac{\Delta c_p}{c_p}\frac{\Delta f}{f}\frac{c_p f}{c} \tag{A-3}$$

Using the notation of Section 3.1.1, Eq. (A-3) is rewritten as

$$Z_{FPI} = Y_P \frac{C_P}{C} + Y_F \frac{F}{C} C_I + Y_I Y_F \frac{C_I F}{C} + Y_I \frac{C_I F}{C} - Y_F \frac{FC_P}{C}$$

$$- Y_P \frac{C_P}{C} F - Y_P Y_F \frac{C_P F}{C}$$

or

$$Z_{FPI} = Y_P \frac{C_P}{C} + \frac{F}{C}\left[C_I(Y_F + Y_I Y_F + Y_I) - C_P(Y_F + Y_P Y_F + Y_P)\right] \quad (13)$$

when $Y_F = 0$, Eq. (13) reduces to

$$Z_{PI} = Y_P \frac{C_P}{C} + \frac{FC_I}{C} Y_I - \frac{FC_P}{C} Y_P$$

$$= Y_I \frac{C_I}{C} F + Y_P \frac{C_P}{C}(1-F) \quad (12)$$

when $Y_P = 0$, Eq. (12) reduces to

$$Z_I = Y_I \frac{C_I}{C} F \quad (11)$$

when $Y_I = 0$, Eq. (12) reduces to

$$Z_P = Y_P \frac{C_P}{C} - F \frac{C_P}{C} Y_P$$

$$= Y_P \frac{C_P}{C}(1-F) \quad (10)$$

when $Y_I = Y_P = 0$, Eq. (13) reduces to

$$Z_F = Y_F \frac{F}{C} C_I - Y_F F \frac{C_P}{C}$$

$$= Y_F \frac{F}{C}(C_I - C_P)$$

$$= Y_F \frac{F}{C} \frac{C - C_P}{F}$$

$$= Y_F(1 - \frac{C_P}{C}) \quad (9)$$

A.2 Derivation of Equation 15

Equation (5) is rewritten for the exact and approximate quantities using capital and lower case letters respectively.

$$R = C(P-f) \tag{A-4}$$

$$r = c(p-f)$$

or

$$r + \Delta r = (c + \Delta c)(p + \Delta p - f - \Delta f) \tag{A-5}$$

whence:

$$\Delta r = p\Delta c + c\Delta p + \Delta c\Delta p - f\Delta c - c\Delta f - \Delta c\Delta f$$

or

$$\frac{\Delta r}{r} = \frac{\Delta c}{c}\frac{pc}{r} + \frac{\Delta p}{p}\frac{pc}{r} + \frac{\Delta c}{c}\frac{\Delta p}{p}\frac{pc}{p} - \frac{\Delta c}{c}\frac{fc}{r} - \frac{\Delta f}{f}\frac{cf}{r} - \frac{\Delta c}{c}\frac{\Delta f}{f}\frac{fc}{r}$$

or in the notation of Section 3.3

$$Z_{RC} = Y_C\frac{pc}{r} + Y_R\frac{pc}{r} + Y_CY_R\frac{pc}{r} - Y_C\frac{fc}{r} - Y_F\frac{cf}{r} - Y_CY_F\frac{fc}{r}$$

$$= \frac{pc}{r}(Y_C + Y_R + Y_CY_R) - \frac{cf}{r}(Y_C + Y_F + Y_CY_F) \tag{A-6}$$

Assuming f negligible compared to P then $r \simeq c_p$ and (A-6) reduces to

$$Z_{RC} = Y_C + Y_R + Y_CY_R \tag{15}$$

APPENDIX B

SAMPLE INPUT AND OUTPUT

OF

COMPUTER PROGRAM STORM

HOURLY RAINFALL, IN HUNDRETHS OF AN INCH

YEAR	MO	DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
1970	4	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	4	12	6	0	26
1970	4	23	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	1	0	0	3	27	57
1970	4	24	17	8	8	5	5	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50
1970	4	27	0	0	0	0	0	0	0	0	0	0	0	0	0	25	9	0	0	0	0	0	0	0	0	0	34
1970	4	30	0	0	0	0	0	0	0	0	10	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36
1970	5	1	0	0	0	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
1970	5	8	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	3
1970	5	11	0	0	0	0	0	0	0	0	0	0	0	0	16	84	38	22	3	0	0	0	0	0	0	0	163
1970	5	12	0	0	0	2	15	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	20
1970	5	13	46	19	1	0	0	0	5	2	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	79
1970	5	14	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	11	0	0	0	0	0	0	0	0	15
1970	5	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	1	1	2	1	9
1970	5	16	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
1970	5	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	2	8	16
1970	5	24	25	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	3	0	8	9	6	2	103
1970	6	1	0	0	0	0	2	11	9	0	0	22	2	0	0	0	6	0	19	17	0	0	0	0	0	2	90
1970	6	5	0	0	0	0	0	1	0	1	5	8	3	1	3	1	0	0	0	0	0	0	0	0	0	0	23
1970	6	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
1970	6	14	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	3	9	9	0	0	0	0	0	36
1970	6	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43	2	0	0	0	0	0	0	0	45
1970	7	8	0	0	0	0	0	0	0	0	0	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	45
1970	7	18	0	0	0	0	0	0	0	0	0	0	11	0	0	0	148	22	20	11	5	13	0	0	0	0	230
1970	7	19	0	0	0	0	4	0	0	0	0	0	0	0	0	0	2	4	9	0	0	0	1	1	0	0	21
1970	7	23	1	0	0	0	0	3	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
1970	7	27	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
1970	7	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	0	0	0	0	57	21	17	130
1970	7	30	43	18	49	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	127
1970	8	19	2	0	3	8	9	6	7	0	0	0	0	29	12	9	0	0	0	0	0	0	0	0	0	0	85
1970	9	3	0	0	0	0	0	0	0	0	0	0	5	2	0	0	0	1	0	0	0	0	0	0	0	0	8
1970	9	4	0	0	0	0	0	0	0	0	5	2	119	9	0	0	0	0	0	0	0	0	0	0	0	0	135
1970	9	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
1970	9	6	0	0	0	0	0	0	0	0	0	0	2	2	1	1	4	0	0	0	0	0	0	0	0	0	10
1970	9	12	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	13	0	19
1970	9	13	0	21	30	2	0	0	0	0	0	0	0	0	0	12	3	0	0	0	0	0	0	0	0	1	69
1970	9	14	0	0	1	11	3	8	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25
1970	9	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	5	39	17	0	1	0	8	0	81
1970	9	18	2	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
1970	9	20	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
1970	9	21	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	15	11	12	17	0	0	56
1970	9	22	0	6	5	31	0	0	4	0	9	9	0	16	1	1	0	0	0	0	6	2	1	13	0	0	104
1970	9	24	10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11
1970	9	26	0	0	2	17	6	1	3	4	6	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43
1970	10	8	1	5	12	5	6	16	27	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	79
1970	10	9	0	0	0	6	11	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37
1970	10	12	1	0	1	1	5	7	8	1	0	1	1	2	2	1	0	0	0	0	0	0	0	0	0	0	31
1970	10	13	0	0	0	0	0	1	0	0	2	2	1	0	0	0	0	0	0	0	0	3	2	0	0	0	11
1970	10	14	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
1970	10	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	3	8
1970	10	20	4	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
1970	10	28	0	1	1	2	4	1	1	6	8	3	1	4	1	4	2	2	0	2	2	0	0	0	0	0	45
1970	11	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	3	7	14
1970	11	2	3	3	4	6	4	9	5	3	4	3	6	9	10	3	0	0	0	0	0	0	0	0	0	0	72
1970	11	9	0	0	0	0	0	0	5	4	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	12
1970	11	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	21	10	4	0	0	0	1	38
1970	11	20	2	12	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21
1970	11	27	0	0	0	0	0	0	3	6	1	2	3	7	3	0	0	0	18	3	0	0	0	0	0	0	46
1970	11	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
1970	11	29	1	3	5	14	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24

END OF RAINFALL DATA.
58 RAINFALL DAYS PROCESSED ENCOMPASSING 225 DAYS (1 YEARS) OF RECORD.

B.1 Rainfall Data for Northwestern Avenue Raingage Station (1970)

OPTION I

WATERSHED DATA

NW	NAMEWS	MXLG	EXPTE	REFF	TRTP	TSUBC	IPACUM
		1	4.600	.700	3.00	.50	1

AREA	RFU	IQU	DVU	DVUMX	WU	POPULA
29.00	1.00	-0	-.00	-.00	-.00	0

DAILY EVAPORATION RATES FOR EACH MONTH,JAN-DEC IN INCHES/DAY
.00 .00 .00 .15 .14 .22 .29 .18 .14 .11 .02 .00

LOSSEQ	CPERV	CIMP	DEPRESSION STORAGE (INCHES)	EERC	EPRC
1	.08	.34	.23	3.0	1.0

INPUT DATA DESCRIBING LAND USE AND POLLUTANTS

LNDUSE	PRCNT	FIMP	STLEN	NCLEAN	DD	POUNDS POLLUTANT PER 100LB DD SUSP	SETL	BOD	N	PO4	BMPN/100LB DD COLI
SINGLE	100.0	38.0	360.0	7	.70	33.300	1.100	1.500	-.000	-.000	-.0

COMPUTED RUNOFF COEFFICIENT FOR WATERSHED IS .17880

FRACTION OF WATERSHED THAT IS IMPERVIOUS IS .3800

OPTION II

WATERSHED DATA

NW	NAMEWS	MXLG	EXPTE	REFF	TRTP	TSUBC	IPACUM
		1	4.600	.700	3.00	.50	1

AREA	RFU	IQU	DVU	DVUMX	WU	POPULA
29.00	1.00	-0	-.00	-.00	-.00	0

DAILY EVAPORATION RATES FOR EACH MONTH,JAN-DEC IN INCHES/DAY
.00 .00 .00 .15 .14 .22 .29 .18 .14 .11 .02 .00

LOSSEQ	CPERV	CIMP	DEPRESSION STORAGE (INCHES)	EERC	EPRC
3	.08	.34	.23	3.0	1.0

LANDUSE	DEPR	ACTIA	SACT	SMAX	RATEIN	PERCMX
SINGLE	.70	.25	1.50	3.50	.03	.05

INPUT DATA DESCRIBING LAND USE AND POLLUTANTS

LNDUSE	PRCNT	FIMP	STLEN	NCLEAN	DD	POUNDS POLLUTANT PER 100LB DD SUSP	SETL	BOD	N	PO4	BMPN/100LB DD COLI
SINGLE	100.0	38.0	360.0	7	.70	33.300	1.100	1.500	-.000	-.000	-.0

FRACTION OF WATERSHED THAT IS IMPERVIOUS IS .3800

B.2 Watershed Data

PAGE 1 ANALYSIS NO 1 ROSS ADE UPPER WATERSHED

QUANTITY ANALYSIS

TREATMENT RATE = .0000 IN/HR, .0 CFS, .000 MGD
STORAGE CAPACITY= .0000 INCHES, .0 AC-FT, .000 MG

N.W.AVE RAINGAGE STATION(1970)
NW

OPTION I

EVENT	---D A T E--- YEAR	MO	DY	HR	HRS NO STORAG	---RAINFALL--- DRTN	HRS	INCH	RUNO INCH	OUTF INCH
****1	*********			2 *3	*****4	***5	***6	***7	**7A	**7B
1	70	4	20	22	21	3	3	.18	.03	.03
2	70	4	23	24	71	8	8	.77	.13	.13
3	70	4	27	14	78	3	3	.34	.02	.02
4	70	4	30	10	65	2	2	.26	.02	.02
5	70	5	11	14	266	5	5	1.47	.25	.25
6	70	5	12	5	10	2	2	.15	.02	.02
7	70	5	13	1	18	4	4	.66	.11	.11
8	70	5	13	7	2	4	4	.13	.02	.02
9	70	5	24	1	254	3	3	.43	.06	.06
10	70	5	24	18	14	7	7	.60	.09	.09
11	70	6	1	10	176	3	3	.24	.04	.04
12	70	6	1	15	2	5	5	.42	.07	.07
13	70	6	14	18	310	3	3	.18	.02	.02
14	70	6	24	16	235	3	3	.45	.04	.04
15	70	7	8	10	327	2	2	.45	.04	.04
16	70	7	18	15	243	7	7	2.19	.36	.36
17	70	7	29	17	259	2	2	.35	.02	.02
18	70	7	29	22	3	8	8	2.22	.39	.39
19	70	8	19	6	480	3	3	.13	.02	.02
20	70	8	19	12	3	4	4	.50	.08	.08
21	70	9	4	11	379	3	3	1.28	.20	.20
22	70	9	13	2	204	4	4	.53	.08	.08
23	70	9	13	14	8	3	3	.15	.02	.02
24	70	9	14	4	11	6	6	.24	.04	.04
25	70	9	17	18	80	12	12	.69	.11	.11
26	70	9	21	20	86	4	4	.40	.06	.06
27	70	9	22	2	2	4	4	.42	.07	.07
28	70	9	22	7	1	9	9	.40	.07	.07
29	70	9	22	19	3	5	5	.22	.04	.04
30	70	9	26	5	77	7	7	.24	.04	.04
31	70	10	8	5	281	5	5	.56	.10	.10
32	70	10	9	5	19	2	2	.11	.01	.01
33	70	10	9	8	1	2	2	.20	.03	.03
34	70	10	12	8	70	8	8	.08	.01	.01
35	70	10	14	3	35	2	2	.10	.01	.01
36	70	10	28	9	340	12	12	.29	.04	.04
37	70	11	1	24	99	16	16	.79	.14	.14
38	70	11	19	18	410	4	4	.35	.03	.03
39	70	11	19	24	2	5	5	.22	.04	.04
40	70	11	27	11	174	4	4	.13	.02	.02
41	70	11	27	17	2	3	3	.21	.04	.04
42	70	11	29	2	30	5	5	.23	.04	.04
AVE OF	42 EVENTS				30.1*	4.9	4.9	.48	.07	.07
AVE OF	42 OVRFLW EVENTS					4.9	4.9	.48	.07	.07

*EXCLUDING 15 DRY PERIODS

OPTION II

EVENT	---D A T E--- YEAR	MO	DY	HR	HRS NO STORAG	---RAINFALL--- DRTN	HRS	INCH	RUNO INCH	OLTF INCH
****1	*********			2 *3	*****4	***5	***6	***7	**7A	**7B
1	70	4	20	22	21	3	3	.18	.02	.02
2	70	4	23	24	71	8	8	.77	.10	.10
3	70	4	27	14	78	3	3	.34	.01	.01
4	70	4	30	10	65	2	2	.26	.02	.02
5	70	5	11	14	266	5	5	1.47	.30	.30
6	70	5	12	5	10	2	2	.15	.01	.01
7	70	5	13	1	18	4	4	.66	.08	.08
8	70	5	13	7	2	4	4	.13	.02	.02
9	70	5	24	1	254	3	3	.43	.05	.05
10	70	5	24	18	14	7	7	.60	.07	.07
11	70	6	1	10	176	3	3	.24	.03	.03
12	70	6	1	15	2	5	5	.42	.05	.05
13	70	6	14	18	310	3	3	.18	.01	.01
14	70	6	24	16	235	3	3	.45	.03	.03
15	70	7	8	10	327	2	2	.45	.03	.03
16	70	7	18	15	243	7	7	2.19	.54	.54
17	70	7	29	17	259	2	2	.35	.02	.02
18	70	7	29	22	3	8	8	2.22	.64	.64
19	70	8	19	6	480	3	3	.13	.01	.01
20	70	8	19	12	3	4	4	.50	.06	.06
21	70	9	4	11	379	3	3	1.28	.21	.21
22	70	9	13	2	204	4	4	.53	.06	.06
23	70	9	13	14	8	3	3	.15	.01	.01
24	70	9	14	4	11	6	6	.24	.03	.03
25	70	9	17	18	80	12	12	.69	.08	.08
26	70	9	21	20	86	4	4	.40	.04	.04
27	70	9	22	2	2	4	4	.42	.06	.06
28	70	9	22	7	1	9	9	.40	.06	.06
29	70	9	22	19	3	5	5	.22	.03	.03
30	70	9	26	5	77	7	7	.24	.03	.03
31	70	10	8	5	281	5	5	.56	.07	.07
32	70	10	9	5	19	2	2	.11	.01	.01
33	70	10	9	8	1	2	2	.20	.02	.02
34	70	10	12	8	70	8	8	.08	.01	.01
35	70	10	14	3	35	2	2	.10	.01	.01
36	70	10	28	9	340	12	12	.29	.03	.03
37	70	11	1	24	99	16	16	.79	.10	.10
38	70	11	19	18	410	4	4	.35	.02	.02
39	70	11	19	24	2	5	5	.22	.03	.03
40	70	11	27	11	174	4	4	.13	.01	.01
41	70	11	27	17	2	3	3	.21	.03	.03
42	70	11	29	2	30	5	5	.23	.03	.03
AVE OF	42 EVENTS				30.1*	4.9	4.9	.48	.07	.07
AVE OF	42 OVRFLW EVENTS					4.9	4.9	.48	.07	.07

*EXCLUDING 15 DRY PERIODS

B.3 Analysis No. 1

OPTION I

```
AVERAGE ANNUAL STATISTICS FOR  1 YEARS OF RECORD FOR THE PERIOD BEGINNING 700420 AND ENDING 701129
--------------------------------------------------------------------------------------------------

NUMBER OF EVENTS =     42.0
NUMBER OF OVERFLOWS =  42.0
                                        INCHES
                                        ------
PRECIPITATION ON WATERSHED               24.87
SURFACE RUNOFF FROM WATERSHED             3.06    FRACTION OF RAINFALL = .12
OUTFLOW
(SURFACE RUNOFF + DRY WEATHER FLOW)       3.06
DRY WEATHER FLOW DURING TIMES
OF RUNOFF OR STORAGE                       .00    FRACTION OF OUTFLOW  = .00
OVERFLOW TO RECEIVING WATER               3.06    FRACTION OF RAINFALL = .12,  OF RUNOFF =1.00,  OF OUTFLOW =1.00
INITIAL OVERFLOW TO RECEIVING WATER       2.41    FRACTION OF RAINFALL = .10,  OF RUNOFF = .79,  OF OUTFLOW = .79
```

OPTION II

```
AVERAGE ANNUAL STATISTICS FOR  1 YEARS OF RECORD FOR THE PERIOD BEGINNING 700420 AND ENDING 701129
--------------------------------------------------------------------------------------------------

NUMBER OF EVENTS =     42.0
NUMBER OF OVERFLOWS =  42.0
                                        INCHES
                                        ------
PRECIPITATION ON WATERSHED               24.87
SURFACE RUNOFF FROM WATERSHED             3.06    FRACTION OF RAINFALL = .12
OUTFLOW
(SURFACE RUNOFF + DRY WEATHER FLOW)       3.06
DRY WEATHER FLOW DURING TIMES
OF RUNOFF OR STORAGE                       .00    FRACTION OF OUTFLOW  = .00
OVERFLOW TO RECEIVING WATER               3.06    FRACTION OF RAINFALL = .12,  OF RUNOFF =1.00,  OF OUTFLOW =1.00
INITIAL OVERFLOW TO RECEIVING WATER       2.16    FRACTION OF RAINFALL = .09,  OF RUNOFF = .70,  OF OUTFLOW = .70
```

B.4 Average Annual Statistics

ANALYSIS NO. 1

ROSS-ADE UPPER WATERSHED

TREATMENT RATE = .0000 IN/HR
STORAGE CAPACITY = .0000 IN/HR

N.W.AVE RAINGAGE STATION(1970)

OPTION I

YR	MO	DY	HR	T(D)	RAIN (INCHES)	RUNOF (INCHES)
EVENT #1						
70	4	20	22	1	.12	.01
70	4	20	23	2	.06	.01
EVENT #2						
70	4	23	24	1	.27	.04
70	4	24	1	2	.17	.03
70	4	24	2	3	.08	.01
70	4	24	3	4	.08	.01
70	4	24	4	5	.05	.01
70	4	24	5	6	.05	.01
70	4	24	6	7	.07	.01
EVENT #3						
70	4	27	14	1	.25	.00
70	4	27	15	2	.09	.02
EVENT #4						
70	4	30	10	1	.26	.02
EVENT #5						
70	5	11	14	1	.84	.14
70	5	11	15	2	.38	.07
70	5	11	16	3	.22	.04
70	5	11	17	4	.03	.01
EVENT #6						
70	5	12	5	1	.15	.02
EVENT #7						
70	5	13	1	1	.46	.07
70	5	13	2	2	.19	.03
70	5	13	3	3	.01	.00
EVENT #8						
70	5	13	7	1	.05	.01
70	5	13	8	2	.02	.00
70	5	13	9	3	.06	.01

OPTION II

YR	MO	DY	HR	T(D)	RAIN (INCHES)	RUNOF (INCHES)
EVENT #1						
70	4	20	22	1	.12	.01
70	4	20	23	2	.06	.01
EVENT #2						
70	4	23	24	1	.27	.03
70	4	24	1	2	.17	.02
70	4	24	2	3	.08	.01
70	4	24	3	4	.08	.01
70	4	24	4	5	.05	.01
70	4	24	5	6	.05	.01
70	4	24	6	7	.07	.01
EVENT #3						
70	4	27	14	1	.25	.00
70	4	27	15	2	.09	.01
EVENT #4						
70	4	30	10	1	.26	.02
EVENT #5						
70	5	11	14	1	.84	.11
70	5	11	15	2	.38	.10
70	5	11	16	3	.22	.07
70	5	11	17	4	.03	.01
EVENT #6						
70	5	12	5	1	.15	.01
EVENT #7						
70	5	13	1	1	.46	.05
70	5	13	2	2	.19	.03
70	5	13	3	3	.01	.00
EVENT #8						
70	5	13	7	1	.05	.00
70	5	13	8	2	.02	.00
70	5	13	9	3	.06	.01

OPTION I

YR	MO	DY	HR	T(D)	RAIN (INCHES)	RUNOF (INCHES)
EVENT #9						
70	5	24	1	1	.25	.03
70	5	24	2	2	.18	.03
EVENT #10						
70	5	24	18	1	.32	.04
70	5	24	19	2	.03	.01
70	5	24	21	4	.08	.01
70	5	24	22	5	.09	.02
70	5	24	23	6	.06	.01
70	5	24	24	7	.02	.00
EVENT #11						
70	6	1	10	1	.22	.03
70	6	1	11	2	.02	.00
EVENT #12						
70	6	1	15	1	.06	.01
70	6	1	17	3	.19	.03
70	6	1	18	4	.17	.03
EVENT #13						
70	6	14	18	1	.09	.00
70	6	14	19	2	.09	.02
EVENT #14						
70	6	24	16	1	.43	.04
70	6	24	17	2	.02	.00
EVENT #15						
70	7	8	10	1	.45	.04
EVENT #16						
70	7	18	15	1	1.48	.24
70	7	18	16	2	.22	.04
70	7	18	17	3	.20	.04
70	7	18	18	4	.11	.02
70	7	18	19	5	.05	.01
70	7	18	20	6	.13	.02

OPTION II

YR	MO	DY	HR	T(D)	RAIN (INCHES)	RUNOF (INCHES)
EVENT #9						
70	5	24	1	1	.25	.02
70	5	24	2	2	.18	.02
EVENT #10						
70	5	24	18	1	.32	.03
70	5	24	19	2	.03	.00
70	5	24	21	4	.08	.01
70	5	24	22	5	.09	.01
70	5	24	23	6	.06	.01
70	5	24	24	7	.02	.00
EVENT #11						
70	6	1	10	1	.22	.02
70	6	1	11	2	.02	.00
EVENT #12						
70	6	1	15	1	.06	.00
70	6	1	17	3	.19	.02
70	6	1	18	4	.17	.02
EVENT #13						
70	6	14	18	1	.09	.00
70	6	14	19	2	.09	.01
EVENT #14						
70	6	24	16	1	.43	.03
70	6	24	17	2	.02	.00
EVENT #15						
70	7	8	10	1	.45	.03
EVENT #16						
70	7	18	15	1	1.48	.26
70	7	18	16	2	.22	.08
70	7	18	17	3	.20	.08
70	7	18	18	4	.11	.05
70	7	18	19	5	.05	.02
70	7	18	20	6	.13	.06

B.5 Output by Event

TREATMENT RATE = .0000 IN/HR
STORAGE CAPACITY = .0000 IN/HR

N.W.AVE RAINGAGE STATION(1970)

OPTION I

YR	MO	DY	HR	T(D)	RAIN (INCHES)	RUNOF (INCHES)
EVENT 17						
70	7	29	17	1	.35	.02
EVENT 18						
70	7	29	22	1	.57	.09
70	7	29	23	2	.21	.04
70	7	29	24	3	.17	.03
70	7	30	1	4	.43	.08
70	7	30	2	5	.18	.03
70	7	30	3	6	.49	.09
70	7	30	4	7	.17	.03
EVENT 19						
70	8	19	6	1	.06	.01
70	8	19	7	2	.07	.01
EVENT 20						
70	8	19	12	1	.29	.05
70	8	19	13	2	.12	.02
70	8	19	14	3	.09	.02
EVENT 21						
70	9	4	11	1	1.19	.18
70	9	4	12	2	.09	.02
EVENT 22						
70	9	13	2	1	.21	.03
70	9	13	3	2	.30	.05
70	9	13	4	3	.02	.00
EVENT 23						
70	9	13	14	1	.12	.01
70	9	13	15	2	.03	.01
EVENT 24						
70	9	14	4	1	.11	.01
70	9	14	5	2	.03	.01
70	9	14	6	3	.08	.01
70	9	14	7	4	.01	.00
70	9	14	8	5	.01	.00

OPTION II

YR	MO	DY	HR	T(D)	RAIN (INCHES)	RUNOF (INCHES)
EVENT 17						
70	7	29	17	1	.35	.02
EVENT 18						
70	7	29	22	1	.57	.07
70	7	29	23	2	.21	.04
70	7	29	24	3	.17	.04
70	7	30	1	4	.43	.14
70	7	30	2	5	.18	.07
70	7	30	3	6	.49	.21
70	7	30	4	7	.17	.08
EVENT 19						
70	8	19	6	1	.06	.01
70	8	19	7	2	.07	.01
EVENT 20						
70	8	19	12	1	.29	.03
70	8	19	13	2	.12	.02
70	8	19	14	3	.09	.01
EVENT 21						
70	9	4	11	1	1.19	.18
70	9	4	12	2	.09	.03
EVENT 22						
70	9	13	2	1	.21	.02
70	9	13	3	2	.30	.04
70	9	13	4	3	.02	.00
EVENT 23						
70	9	13	14	1	.12	.01
70	9	13	15	2	.03	.00
EVENT 24						
70	9	14	4	1	.11	.01
70	9	14	5	2	.03	.00
70	9	14	6	3	.08	.01
70	9	14	7	4	.01	.00
70	9	14	8	5	.01	.00

OPTION I

YR	MO	DY	HR	T(D)	RAIN (INCHES)	RUNOF (INCHES)
EVENT 25						
70	9	17	18	1	.39	.06
70	9	17	19	2	.17	.03
70	9	17	21	4	.01	.00
70	9	17	23	6	.08	.01
70	9	18	1	8	.02	.00
70	9	18	2	9	.01	.00
70	9	18	4	11	.01	.00
EVENT 26						
70	9	21	20	1	.11	.01
70	9	21	21	2	.12	.02
70	9	21	22	3	.17	.03
EVENT 27						
70	9	22	2	1	.06	.01
70	9	22	3	2	.05	.01
70	9	22	4	3	.31	.06
EVENT 28						
70	9	22	7	1	.04	.01
70	9	22	9	3	.09	.02
70	9	22	10	4	.09	.02
70	9	22	12	6	.16	.03
70	9	22	13	7	.01	.00
70	9	22	14	8	.01	.00
EVENT 29						
70	9	22	19	1	.06	.01
70	9	22	20	2	.02	.00
70	9	22	21	3	.01	.00
70	9	22	22	4	.13	.02
EVENT 30						
70	9	26	5	1	.06	.00
70	9	26	6	2	.01	.00
70	9	26	7	3	.03	.01
70	9	26	8	4	.04	.01
70	9	26	9	5	.06	.01
70	9	26	10	6	.04	.01

OPTION II

YR	MO	DY	HR	T(D)	RAIN (INCHES)	RUNOF (INCHES)
EVENT 25						
70	9	17	18	1	.39	.04
70	9	17	19	2	.17	.02
70	9	17	21	4	.01	.00
70	9	17	23	6	.08	.01
70	9	18	1	8	.02	.00
70	9	18	2	9	.01	.00
70	9	18	4	11	.01	.00
EVENT 26						
70	9	21	20	1	.11	.00
70	9	21	21	2	.12	.02
70	9	21	22	3	.17	.02
EVENT 27						
70	9	22	2	1	.06	.01
70	9	22	3	2	.05	.01
70	9	22	4	3	.31	.05
EVENT 28						
70	9	22	7	1	.04	.00
70	9	22	9	3	.09	.01
70	9	22	10	4	.09	.01
70	9	22	12	6	.16	.02
70	9	22	13	7	.01	.00
70	9	22	14	8	.01	.00
EVENT 29						
70	9	22	19	1	.06	.00
70	9	22	20	2	.02	.00
70	9	22	21	3	.01	.00
70	9	22	22	4	.13	.02
EVENT 30						
70	9	26	5	1	.06	.00
70	9	26	6	2	.01	.00
70	9	26	7	3	.03	.00
70	9	26	8	4	.04	.01
70	9	26	9	5	.06	.01
70	9	26	10	6	.04	.01

B.5 (cont'd)

ANALYSIS NO. 1

ROSS-ADE UPPER WATERSHED

TREATMENT RATE .0000 IN/HR
STORAGE CAPACITY = .0000 IN/HR

N.W.AVE RAINGAGE STATION(1970)

OPTION I

YR	MO	DY	HR	T(D)	RAIN (INCHES)	RUNOF (INCHES)
EVENT 31						
70	10	8	5	1	.06	.01
70	10	8	6	2	.16	.03
70	10	8	7	3	.27	.05
70	10	8	8	4	.07	.01
EVENT 32						
70	10	9	5	1	.11	.01
EVENT 33						
70	10	9	8	1	.20	.03
EVENT 34						
70	10	12	8	1	.01	.00
70	10	12	10	3	.01	.00
70	10	12	11	4	.01	.00
70	10	12	12	5	.02	.00
70	10	12	13	6	.02	.00
70	10	12	14	7	.01	.00
EVENT 35						
70	10	14	3	1	.10	.01
EVENT 36						
70	10	28	9	1	.08	.00
70	10	28	10	2	.03	.01
70	10	28	11	3	.01	.00
70	10	28	12	4	.04	.01
70	10	28	13	5	.01	.00
70	10	28	14	6	.04	.01
70	10	28	15	7	.02	.00
70	10	28	16	8	.02	.00
70	10	28	18	10	.02	.00
70	10	28	19	11	.02	.00

OPTION II

YR	MO	DY	HR	T(D)	RAIN (INCHES)	RUNOF (INCHES)
EVENT 31						
70	10	8	5	1	.06	.01
70	10	8	6	2	.16	.02
70	10	8	7	3	.27	.03
70	10	8	8	4	.07	.01
EVENT 32						
70	10	9	5	1	.11	.01
EVENT 33						
70	10	9	8	1	.20	.02
EVENT 34						
70	10	12	8	1	.01	.00
70	10	12	10	3	.01	.00
70	10	12	11	4	.01	.00
70	10	12	12	5	.02	.00
70	10	12	13	6	.02	.00
70	10	12	14	7	.01	.00
EVENT 35						
70	10	14	3	1	.10	.01
EVENT 36						
70	10	28	9	1	.08	.00
70	10	28	10	2	.03	.00
70	10	28	11	3	.01	.00
70	10	28	12	4	.04	.01
70	10	28	13	5	.01	.00
70	10	28	14	6	.04	.01
70	10	28	15	7	.02	.00
70	10	28	16	8	.02	.00
70	10	28	18	10	.02	.00
70	10	28	19	11	.02	.00

OPTION I

YR	MO	DY	HR	T(D)	RAIN (INCHES)	RUNOF (INCHES)
EVENT 37						
70	11	1	24	1	.07	.01
70	11	2	1	2	.03	.01
70	11	2	2	3	.03	.01
70	11	2	3	4	.04	.01
70	11	2	4	5	.06	.01
70	11	2	5	6	.04	.01
70	11	2	6	7	.09	.02
70	11	2	7	8	.05	.01
70	11	2	8	9	.03	.01
70	11	2	9	10	.04	.01
70	11	2	10	11	.03	.01
70	11	2	11	12	.06	.01
70	11	2	12	13	.09	.02
70	11	2	13	14	.10	.02
70	11	2	14	15	.03	.01
EVENT 38						
70	11	19	18	1	.21	.00
70	11	19	19	2	.10	.02
70	11	19	20	3	.04	.01
EVENT 39						
70	11	19	24	1	.01	.00
70	11	20	1	2	.02	.00
70	11	20	2	3	.12	.02
70	11	20	3	4	.07	.01
EVENT 40						
70	11	27	11	1	.03	.00
70	11	27	12	2	.07	.01
70	11	27	13	3	.03	.01
EVENT 41						
70	11	27	17	1	.18	.03
70	11	27	18	2	.03	.01
EVENT 42						
70	11	29	2	1	.03	.00
70	11	29	3	2	.05	.01
70	11	29	4	3	.14	.03
70	11	29	5	4	.01	.00

OPTION II

YR	MO	DY	HR	T(D)	RAIN (INCHES)	RUNOF (INCHES)
EVENT 37						
70	11	1	24	1	.07	.01
70	11	2	1	2	.03	.00
70	11	2	2	3	.03	.00
70	11	2	3	4	.04	.01
70	11	2	4	5	.06	.01
70	11	2	5	6	.04	.01
70	11	2	6	7	.09	.01
70	11	2	7	8	.05	.01
70	11	2	8	9	.03	.00
70	11	2	9	10	.04	.01
70	11	2	10	11	.03	.00
70	11	2	11	12	.06	.01
70	11	2	12	13	.09	.01
70	11	2	13	14	.10	.02
70	11	2	14	15	.03	.01
EVENT 38						
70	11	19	18	1	.21	.00
70	11	19	19	2	.10	.01
70	11	19	20	3	.04	.01
EVENT 39						
70	11	19	24	1	.01	.00
70	11	20	1	2	.02	.00
70	11	20	2	3	.12	.02
70	11	20	3	4	.07	.01
EVENT 40						
70	11	27	11	1	.03	.00
70	11	27	12	2	.07	.01
70	11	27	13	3	.03	.00
EVENT 41						
70	11	27	17	1	.18	.02
70	11	27	18	2	.03	.00
EVENT 42						
70	11	29	2	1	.03	.00
70	11	29	3	2	.05	.01
70	11	29	4	3	.14	.02
70	11	29	5	4	.01	.00

B.5 (cont'd)